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THE SCIENTIFIC DISPOSAL OF CITY SEWAGE: HISTORICAL DEVELOPMENT AND PRESENT STATUS OF THE PROBLEM

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The disposal of waste is a fundamental problem for all living organisms. As the body takes in food and builds it up into its own wonderful structure, so it must continually break down and give off waste products, which, as a rule, if they accumulate prove poisonous to the organism itself. And as this is the case with the individual, so is it still more the case when large numbers of organisms are closely congregated together in communities. Nevertheless the attempt at scientific waste disposal is a comparatively recent one. It really dates from the epoch-making report of the Health of Towns Commission of Great Britain in 1844, which revealed such astonishing conditions with regard to the decomposing organic matter, and the filth of all kinds which had accumulated in British cities, that it aroused British sanitarians to a strong movement for the amelioration of these conditions, and led to the development of the filth theory of disease — the theory that disease is bred in heaps of decomposing filth. This theory we now know to be wrong in its essential assumption that infective material is created *de novo* by decaying organic matter; yet it was right in laying

emphasis on filth as a carrier of disease. The wonderful administrative work of the British sanitarians, acting on this partially erroneous theory, effected the greatest sanitary progress which has probably ever been known; so that whereas in 1815 the sewers of London were simply drains to carry off the storm water, the discharge of sewage into them being forbidden by law, in 1847, only three years after the report of the Health of Towns Commission, it was made obligatory to discharge all sewage into those drains.

The water carriage system, in which the sewage is diluted as promptly as possible with a large volume of water, was quickly introduced in England, and has since followed in other countries. Thus the problem of disposal was shifted one step away from the individual; instead of the individual having a small amount of waste to dispose of, the municipality has now a very much larger problem on its hands — the disposal of all the waste materials diluted with a great volume of water. For example, in Boston, on one side of the city, known as the South Metropolitan District, it is necessary in every year to dispose in some way of 1,600 tons of nitrogen as free ammonia alone, representing an enormous quantity of organic matter; and the problem is made so much more difficult by reason of the fact that the organic matter is diluted with thirty billion gallons of water.

In American sewages we find only one part in 1,000 of solid matter; in other words, there are 999 parts of water to be handled, or somewhat more than that, for every part of solid matter. The dangerous elements making up the single part in 1,000 with which we are particularly concerned in sewage disposal may be classed under three heads: organic matter, mineral matter, and bacteria. The mineral matter is harmful only under exceptional conditions, when large amounts of industrial wastes enter the sewers, and need not be considered tonight. The bacteria may be harmful when the sewage is so discharged as to reach some source of food or water supply. In the case of the water supply it is hardly fair to expect protection from the sewage expert. It is a very difficult matter indeed to produce a germ-free effluent by any process of sewage disposal, and we are now taking the position that no surface water should be used for drinking purposes without being filtered. So I think sewage experts have a right to feel that the responsibility for disease caused by the discharge of sewage into water rests most heavily upon the water supply experts. This general proposition must be modified in the special case where sewage is discharged into ponds

and estuaries from which shellfish are taken. Here there can be no question of purifying the shellfish. It is necessary either to abandon the taking of shellfish from such waters or to purify the sewage in such a way as to remove the disease germs. This is a problem which may prove of increasing importance during the next few years, and which may make it necessary to produce a sterile effluent, or, at least, one free from pathogenic bacteria. As a rule, however, in questions of sewage disposal it is not the bacteria but the decomposing organic matter with which we are chiefly concerned. Such organic matter is composed of unstable molecules, imperfectly oxidized, which can be disposed of in two ways. First, it may decompose, putrefy, break down, with the production of offensive gases of decomposition, creating a nuisance, and in some cases, as in one or two heavily polluted rivers in Massachusetts, actually endangering the health of adjacent communities. Or, secondly, under the influence of oxygen it may undergo another process that we call nitrification, a slow burning or combustion which converts the organic matter into nitrates, or other mineral substances, without the production of foul odors and in a wholly satisfactory way. Organic matter must either putrefy or nitrify, and the aim of sewage treatment is to nitrify it. This is a difficult problem, because it involves the supply to that organic matter of one to three times its weight of oxygen, with the special conditions under which the oxygen and the organic matter will unite.

Disposal by Dilution. — The most obvious way to dispose of sewage is to throw it into the nearest body of water. Before true sewers existed the natural drains discharged into the nearest water course, and when they became filled with polluting matter the same plan was followed. Sometimes this works very well. If the volume of sewage discharged into a stream is sufficiently small, there may be enough oxygen to unite with the organic matter and enough organic life in the stream to effect that union. Under such condition there results a self-purification of the stream of a very satisfactory type. The problem changes, however, when the volume of sewage exceeds the maximum which may be absorbed by a given stream, which may be stated as one part of sewage to fifty parts of water. When that limit is exceeded, when the limit of available oxygen for the oxidation of organic matter is passed, then the conditions of putrefaction are set up. It is like Mr. Micawber's philosophy: "Annual income twenty pounds, annual expenditures nineteen ought and six, result happiness. Annual income twenty pounds,

annual expenditures twenty pounds ought and six, result misery." Up to a certain point everything goes well, but beyond that point conditions are totally changed, and instead of a self-purifying stream you find a foul septic tank such as Boston has possessed for some time in front of her most costly residential street, in the Fens basin. Dilution then — the discharge of sewage into water — is limited by the volume of sewage in relation to the body of water into which it is to discharge. On the seacoast the conditions for purification by dilution are ideal; and with large rivers like the Mississippi this method may be followed very satisfactorily. In smaller streams we get the septic tank condition of which I have spoken. In Massachusetts alone there are at least seven rivers so polluted as to become a public nuisance for a part of their course. The Neponset at Hyde Park and the Blackstone River below Worcester will occur to all as conspicuous examples.

Disposal on Land. — A second obvious method of sewage disposal is discharge on the surface of the soil; and this method has been followed from time immemorial. In the little city of Bunzlau in Prussia there was a public water supply as early as 1559, piped from a spring, and in connection with it was installed a sewerage system and a system of disposal on a sewage farm. At this time it was thought that you could not only dispose of sewage satisfactorily by discharging it on land, but that a good deal of profit would come from the fertilizing effect of the material. So the practice of sewage farming spread, and in England, just after the period of sanitary reform in the early sixties, grew up very rapidly. A number of irrigation areas successfully operated today were laid out in England at that time. The largest and most famous examples of this process are the sewage farms at Paris and Berlin. In Berlin the flow of sewage from a population of 1,750,000 is treated on 23,000 acres of land at a rate of 3,000 gallons per acre per day. Crops are cultivated and the farm is operated with fair success, the operation being carried out by convicts under military discipline. The process of irrigation, or sewage farming, seems to work satisfactorily wherever there is available an ample area of suitable soil, but in many cases such large areas cannot be found. In many parts of England and in some places on the continent of Europe the process is impracticable because it is impossible to get sufficient land of the right kind.

There is a certain sanitary danger in the process of sewage farming if the crops grown are not properly regulated. A recent English com-

mission has recommended that no crops for human consumption be grown on fields used for the disposal of sewage. That is an extremely conservative position; but certainly, I think, crops should be limited to those food substances which are to be cooked before eating. The economy of the system of sewage farming is still more doubtful. It is never good policy to recover something valuable which costs more to recover than it is worth after recovery. That appears frequently to have occurred in the experience of those who have tried sewage farming, since in many instances the expenses of conducting the farms are really not paid by the crops grown on them. This does not hold good in arid regions where sewage is valuable, not only for its manurial elements, but for the water it contains; in the far West we find that the sewage farm has a most important place. The city of Pasadena, for example, has operated a sewage farm for twelve years. Alfalfa and crops of that character were grown at first with poor success, because, the crop being so near the ground, it was impossible to cultivate it properly and keep the surface open. The city is now growing mainly walnuts, with considerable profit. In 1903 the receipts from the farm were about eleven thousand dollars and the expenses about six thousand dollars, and out of the profits the original cost of buying the land is being paid off at a rapid rate. In a country of that sort the process is quite profitable, and no doubt sewage farming will have a large future in the arid regions of the West. In the East, however, where there is plenty of water, the value of the process is extremely doubtful, if for no other reason than because of the difficulty of securing economical administration under American municipal conditions.

Disposal by Intermittent Filtration. — The process of sewage purification on land soon underwent a development along more intensive lines. As early as 1865 the German engineer, Mueller, urged the disposal of sewage through land at a more rapid rate than is possible on the ordinary sewage farm. He understood the nature of the process, and knew that it was carried out by organic life; and in 1878 he patented a system "for the disinfection, purification, and utilization of sewage by the scientific cultivation of yeast-like organisms." His work, however, made no lasting impression. In 1870 the subject was approached along a different line by the English experts of the Rivers Pollution Commission under the leadership of Frankland. These experimenters failed to grasp the biological character of the process, but they understood its chemistry and showed that sewage could be successfully

purified by filtration through various soils, at much higher rates than those used on sewage farms. This principle, worked out by Frankland, was applied in practice as early as 1871 by Bailey-Denton at Merthyr-Tydfil in Wales, where a filtration area was so operated as to care for 60,000 gallons per acre per day for some years.

It was only by work in this state, however, that these various lines of investigation were brought together in so conclusive a form that the importance of the process of intermittent filtration through sand was generally understood. The difficulties experienced by Worcester through the pollution by its sewage of the Blackstone River and the proposition to treat the sewage of Boston and the cities lying to the north, on the Saugus marshes, made sewage disposal an urgent question in Massachusetts in the early eighties. As a result of these conditions the Lawrence Experiment Station of the State Board of Health was founded in 1887 for the study of the sewage purification problem. There, under the leadership of Mr. Hiram F. Mills, with the coöperation of Professor T. M. Drown and Professor W. T. Sedgwick, were carried out the series of experiments since rightly spoken of as classic. Ten circular cypress tanks 17 feet in diameter and 6 feet deep were filled with various filtering materials — sand, gravel, peat, river silt, loam, garden soil, and clay. The fine materials like peat, garden soil, and clay soon clogged, but the beds of sand worked to admiration, receiving sewage above and yielding a clear, bright spring water below. Some of the original tanks have been operated from the day of their installation to the present, a period of over seventeen years, with continuously good results.

The Massachusetts investigators established very clearly that the purification was an oxidizing process, carried out by bacteria living in the sand, and that a rich supply of oxygen was necessary for their activity. In order to supply the oxygen it was necessary to dose the filters intermittently, putting on perhaps one dose a day in an amount of some 60,000 gallons per acre. These experiments led at once to the installation of a number of intermittent sewage filters in Massachusetts, and in 1903 we had twenty-three in operation in different parts of the state, the best known being those at Marlboro, Brockton, Framingham, Gardner, and Clinton; some of them have been in operation now for over ten years. It has been found that a certain amount of solid material accumulates on the surface of such beds, but the material is of a stable nature, not subject to decay, and can be

scraped off at intervals and removed at some expense for labor. Cold winter weather interferes somewhat with the efficiency of the process; but by ridging the beds so that the sewage may flow in furrows under the ice, it is possible with most of the filters in Massachusetts to treat the sewage all the year round. Altogether, intermittent filtration has proved a very satisfactory method of disposal in regions covered with glacial drift, like New England, where large areas of coarse sand are easily available. When, however, you come to a country like New Jersey, where the soil is largely clay, or to many districts in England, where the soil is chalky or rocky and areas of sand are not to be found, intermittent filtration becomes almost impossible, because the cost of filters artifically constructed to operate at such low rates would be prohibitive.

The Septic Tank. — It was necessary in England to develop some new and more rapid method, and as a result three main processes have come into use. The first of these, the septic tank, is designed as a prelude to the ordinary nitrifying process. It is the logical development of the cesspool and of the *fosses fixées*, used in France by Mouras as early as 1860. The principle — that the storing of sewage without access of air led to a sort of fermentation, or ripening, which removed a considerable portion of the solid material — was patented in 1882. Scott-Moncrieff, an English engineer, in 1891 used the same process in what he called a cultivation tank, and in 1894 one was installed at Urbana, Illinois, by Professor Talbot. The process did not attain wide popularity, however, until after 1895, when Donald Cameron, of Exeter, England, gave it the picturesque name of the septic tank. Cameron's relation to the septic tank is much the same as that of the Massachusetts State Board of Health to the process of intermittent filtration through sand. As in the latter case, the principle of the liquefying tank was known before, but it was Cameron who showed the practical importance of the process. He first used a closed tank, but he soon found that this was needless; it was only necessary to allow the liquid to flow slowly through any tank, so as to have a storage of about twenty-four hours, the exact length of time varying with different sewages. Under such conditions decompositions take place, which remove from 60 to 70 per cent. of the suspended solids, turning a part into liquid form, giving off a part as gas, about $7\frac{1}{2}$ gallons of gas to 100 gallons of sewage, and storing a certain amount of solids in the tank. The proportion of the solids destroyed in the tank — digested, so to speak — varies with different

sewages and with the same sewage, at different times, under conditions not thoroughly understood. It was claimed at first that all the solids settled out would be liquefied in the septic tank, but this is not true; a portion only disappears, and most tanks must be opened once or twice a year for the removal of sludge.

The Contact Bed. — Meanwhile progress was being made along a different line. The chemist of the London County Council, Mr. W. J. Dibdin, undertook in the early nineties to devise some more rapid method of sewage disposal than that worked out at Lawrence. He first tried experiments in Barking, at one of the outfalls of the London system, in which he passed sewage through coke and stone in iron cylinders. Finding the process fairly satisfactory, he laid out a one-acre bed filled with coke, made tight — so that he could fill it with sewage, allow it to stand for a certain period, and then empty it. This he called the contact system, because the sewage is held in contact with the coke by the closing of the outlet. In further experiments at Sutton in Surrey, Dibdin developed the double contact system, carrying the sewage treated in one contact bed to another contact bed and treating it again. By each contact about half the impurities in the applied liquid are removed. It has been found that in the construction of contact beds almost any hard, smooth material may be used, the bed being simply a tight box for holding it. Coal and coke are particularly favorable, though stone or almost any other hard substance may be used. The size of the pieces of material, whatever it may be, varies from $\frac{1}{8}$ of an inch to $1\frac{1}{2}$ inches. The beds are commonly made from 3 to 6 feet deep, or thereabouts, but the depth does not seem to be of great importance. The sewage is run slowly into the bed, allowed to stand for a certain time, generally two hours, and then discharged, three or four fillings being made in the twenty-four hours.

The effluent from a double contact system is of good quality, so that it will not decay and can be discharged into a river with safety. The worst difficulty with the method is that there is considerable stoppage or clogging of the beds, due to settling, due to breaking down of the material, due to the growth of organisms in the bed, and partly to the deposition of solid mineral matter in its interior. Stoppage due to breaking down may, of course, be controlled somewhat by using hard material. Stoppage due to the growth of organisms can be checked to a considerable extent by a proper resting of the beds. It apparently does not tend to go beyond a certain point. The loss of

capacity or clogging due to the deposition of mineral matter is more serious, and with many sewages appears to necessitate the renewal of the beds at intervals. After five years in some English plants, for instance, it has been found that the beds must all be dug over and refilled.

The process in the contact bed is a very complicated one, since it involves the alternation of two conditions, the aërobic and the anaërobic. During the full period the organic elements are absorbed by the bacterial films on the stones, and during the empty period the principal part of the purification goes on with free access of air. When the next dose of sewage enters the bed there is an entire reversal of conditions with the setting up of anaërobic fermentations, and the success of the process depends on a delicate balance between the two conditions.

The Trickling or Sprinkling Filter. — The third process developed in England was the process known as trickling filtration. In some of the early Lawrence experiments sewage was passed through rather coarse material, and air was forced in from below to check the flow and to supply oxygen for nitrification. Lowcock at Malvern in England installed a plant on this plan in 1892, and in 1894 Colonel Waring carried out experiments with a similar process at Newport, having taken out a patent on it three years before. Theoretically, this seems to be a satisfactory process for combining the necessary elements — sewage, bacteria, and oxygen — but it is almost impossible in practice to supply sufficient oxygen. To insure success it would be necessary to supply from three to five times as much air as there is sewage purified.

The filtration of sewage through coarse material under continuously aërobic conditions was finally worked out, not by forced aëration, but by sprinkling the sewage over the whole surface of the filter bed in a continuous fine spray, so that the oxygen went in along with it, the sewage never filling the tank but continuously trickling through the filtering material. A filter of this type made of broken chalk was first built by Stoddart in 1893 and exhibited by him at Bristol in England. Meanwhile Corbett, of Salford, had worked out a similar idea; Scott-Moncrieff, Ducat, and others contributed to the development of this type of purification. One of the advantages of the trickling bed system is the extreme simplicity of its construction. It is only necessary to have a heap of material over which the sewage can trickle. It needs, of course, some kind of floor sloped to carry off the drainage, but aside from that the material used can be held together by wooden palings,

or iron bands, or any very simple structure around the outside. The depth is generally 4 feet or over, and, as in the case of the contact bed, any hard material may be used, varying in size from $\frac{1}{8}$ inch to $1\frac{1}{2}$ inches.

The most serious difficulty is in regard to the distribution of the sewage. It must be so applied as to pass through slowly and well mixed with air. Colonel Ducat used tipping buckets, a series of triangular troughs which discharged at intervals, splashing little dashes of sewage over the surface. Stoddart used a trough, from which the sewage overflowed continuously, dripping off from numerous points below; this was good in theory, but difficult to keep working in practice, because the troughs buckle and any difference in level prevents an even distribution. At Salford they used sprays with fixed pipes, like a series of fountains, and many of the English plants are equipped with complicated revolving mechanisms like lawn sprinklers. The most cumbrous of all these contrivances is a radial carrier which moves round and round the bed, its extremity revolving on the wall at the periphery, — dripping sewage as it goes. The rates which may be obtained by the trickling process are very high. The sewage farm will take perhaps an extreme of 10,000 gallons, the intermittent sand filter perhaps 100,000 gallons, and the contact bed 500,000 or 600,000 gallons per acre per day; the trickling filter, on the other hand, easily treats 2,000,000 gallons per acre per day, giving an effluent on the whole better than the contact bed, though not so good as the sand filter. It contains a considerable amount of suspended solids, and does not look as clear as the effluent from the contact bed. But the effluent analyzes well and keeps well, which are the principal points to be considered. Furthermore, its solids may be easily removed by a short period of sedimentation.

Progress in England. — The early English research on what are called the biological methods — although the intermittent filter is a biological method, the name has been particularly applied to the contact and trickling systems — led first to the construction of contact beds. At Exeter, for example, the double contact system was installed. At London it was recommended that the sewage should be treated in septic tanks and single contact beds, although the plant has not yet been begun. At Manchester, experiments in 1899 led to the recommendation of septic tanks, with double contact beds; and forty-eight acres of first contact filters are already in operation. The second contact beds have not yet been built, and the work of the primary filters has not been altogether

what was hoped. The next important experiments were carried out at another great manufacturing centre, Leeds, and there the contact system received a setback. It was found that the beds clogged so badly, with so great a loss of capacity, that the cost of renewal would be prohibitive. By the use of the trickling filter, however, the sewage could be well purified, and the installation of trickling filters has been planned, though not yet executed. At Birmingham the problem was next attacked, and the experts came to the conclusion that the trickling filter is best adapted to local conditions; construction has already been begun. At the present time, while the sewage farm exists in a number of English cities, no new ones are likely to be laid out and the old ones will be gradually abandoned, in all probability. The tendency now is toward the installation of septic tanks and trickling filters. The tide may change again in a few years more, but at present these are the popular systems in English practice.

European Practice. — In Germany progress in sewage treatment has been very slow, much slower than in England. The problem has not pressed so hard, the population being less dense and the rivers larger. It has been possible, as a rule, where sewer systems exist to discharge the sewage directly into streams. Some admirable work has indeed been carried out at the Hamburg Testing Station, under Dr. Dunbar, particularly with relation to the theory of the action of the contact bed; and within the last four years a testing station has been founded in Berlin which has yielded important results. As yet the septic tank has not found favor in Germany — whether on account of carelessness in operation, or on account of the large amount of industrial waste materials in the sewage, is not quite clear. In the use of the contact system it has been found necessary to renew the beds quite often, even once or twice a year, a necessity which the German engineers appear to regard with equanimity. The trickling filter is just beginning to be known, and at Berlin is awakening some enthusiasm. Progress in Germany has only followed that in England; and on the rest of the continent practically nothing has been done except in the line of sewage farming. French engineers have recently visited England and carried home news of the biological experiments; but that is practically all.

Conditions in the United States. — In the United States the problem is a diverse one. As in the case of water purification, local conditions in different parts of the country must be met by totally different methods. Here in Massachusetts the intermittent filter is perfectly satis-

factory, and probably will be used for a long time to come. West of the Alleghanies it is often impossible to install such filters, because the required areas of sand are not available. In the Middle West we generally find the septic tank combined with the sand filter, because it is thus possible to treat the sewage at higher rates. Contact beds and one or two interesting trickling filters have been installed in these regions. The question of sewage purification in the Middle West will largely be controlled by the results of the experiments just completed at Columbus. Columbus is the first American city — the Lawrence Station being, of course, a state institution — to approach the subject of sewage purification in a rational way. It bids fair to be the model sanitary city of the country, with unique and interesting systems of sewage disposal and water purification, and probably a fine garbage disposal plant as well. About a year ago the city called in Messrs. Hering and Fuller to investigate and report on the best method of sewage treatment, and appropriated nearly fifty thousand dollars for experimental work. A fine experiment station was equipped, in which studies were made of over forty separate methods of disposal. The experts have finally reached the conclusion that the best treatment for Columbus sewage is by the use of the septic tank, followed by the trickling filter and this again by sedimentation; and they are now proceeding with the construction of what will be the largest plant in the country, including ten acres of trickling filters. This will surely lead to the construction of numerous similar plants in regions where conditions are similar to those at Columbus.

Experiments at the Technology Experiment Station. — At the Sewage Experiment Station connected with the Massachusetts Institute of Technology experiments on the treatment of Boston sewage were begun a year before those at Columbus, but we are prepared at present to make only a preliminary report. We found, in the first place, that the sewage of the South Metropolitan District is a fairly strong city sewage — a sewage from a city sewered on the combined system, which receives street washings as well as household waste — peculiar only in that it contains a somewhat large amount of suspended matter and considerable sea water, which backs up through leaking tide gates. The first problem which always confronts the engineer in the disposal of sewage is the question of the removal of solids, and it is necessary to distinguish between two or three kinds of solids. In the first place, there are large floating objects, such as rags, bits of wood, etc., which must always be

removed by screening. In the next place, we find rather coarse mineral matter, gravel, etc., from street washings. This will settle out quite readily if, for example, the flow be checked to half a foot per second for a very few minutes. Material of this sort, which we call detritus, must always be removed in any system. It is almost entirely inorganic, of such a nature, therefore, as not to require purification. We have spread the detritus removed at our Albany Street Station during the whole period of experimentation, in the yard of the station without causing a nuisance. When, however, you consider the more finely divided matter, organic in nature, which will settle out only if you reduce the flow to one-tenth of a foot per second for several hours, the difficulty becomes more serious. This finely divided suspended matter may be removed in several ways. The old method for its removal was to treat the sewage with chemical precipitants, but the chemicals are costly and increase the amount of sludge to be handled; only in exceptional cases is that method now used. In such cities as Worcester, where the sewage contains large amounts of certain industrial waste materials, which hinder the biological process and favor the chemical process, precipitation is useful; but from a general consideration of the problem chemical treatment may be dismissed. There are, then, besides the use of chemical precipitants three alternatives with regard to the organic suspended matter. You may either leave it in the sewage to be treated afterward in the contact or trickling filter or sand bed, or you may take it out by plain sedimentation or by the septic tank. The difference between plain sedimentation and the septic tank is simply that in the septic tank the flow is continuous; the tank is not emptied, and the accumulation that settles out is maintained in contact with the material that flows over it. The removal of the sludge is due always to sedimentation. In the septic tank you store the sludge after removing it, and allow the bacteria to liquefy a part. That might seem a clear gain in the use of the septic tank as compared with plain sedimentation; and the septic process certainly disposes of a certain portion of the sludge by liquefaction, the amount varying with the special sewage treated. Furthermore, the actual removal of solids from the effluent is probably greater, from the liquefaction of particles too fine to settle out. The idea that a favorable action on soluble matter is exerted in the septic tank which makes the later nitrifying process easier is very doubtful. There is no evidence of any favorable action; there is, on the other hand, evidence that the septic process may

exercise an unfavorable action on the sewage, producing poisonous substances which interfere with proper oxidation. At Andover in this state it has been found more difficult to treat sewage which has been septicized than crude sewage. In our own experiments we have found that sewage which has been septicized is much more difficult to handle than crude sewage. This appears to be largely due in our case to the presence of calcium sulphate from the sea water, which decomposes in the septic tanks and forms harmful compounds of sulphur. Such a condition must occur, not only in marine cities, but in some inland cities where there are hard waters. We are not quite prepared to say that the septic tank cannot be used in some form with Boston sewage. It may be possible by limiting the action to a brief period, or by subsequent aëration, to avoid hampering the nitrifying bacteria. Along those lines we are still experimenting.

The third alternative to septic treatment or sedimentation is to put the sewage directly on the nitrifying beds, whether contact, sand, or trickling filters. The tendency in England is almost entirely against any such action. They think there that the septic treatment or very thorough sedimentation is absolutely necessary, and, indeed, with many sewages it is. Personally, I do not believe it is safe to say that it is necessary with all sewages. There is no doubt that if you do not do it you will get sludge in your sand bed, contact bed, or trickling filter, and that will sometimes necessitate the renewal of filtering material. Also, there is no doubt that sludge is much harder to remove from the contact or trickling bed than from the septic tank. But, on the other hand, there is some evidence that the sludge is very much less in amount in the contact or trickling bed than in the septic tank, because the oxidizing processes going on in the tank consume a large proportion. The difficulty of sludge removal from the contact bed or trickling filter must be balanced against the cost of the installation and operation of the septic tank or sedimentation basin. Only experimentation in each particular case will determine what method is most desirable for the sewage in hand.

Disposal of Boston Sewage. — With regard to final purifying processes, we have found in our experiments that crude Boston sewage can be treated in sand filter beds at quite a high rate, at the rate of 400,000 gallons per acre per day. That rate, of course, is higher than could be attained in practice, because in our small experimental tanks we can get the sewage distributed very evenly over the surface of the beds, and be-

cause they are protected from the severity of winter. We are anxious, however, that the attempt should be made with filters in actual operation to use higher rates than are now common on sand filter beds. We are inclined to think that the sand filter has never been pushed quite as hard as it might be. Of course, with higher rates you get more sludge on the surface, which will mean more costly operation. But it is a question whether it will cost much more to get 200,000 gallons through one acre than to get 200,000 gallons through two acres. With double contact beds we have found it possible to treat Boston sewage at a combined rate on two beds of 700,000 gallons per acre per day. Clogging occurs, which would probably render renewal of the first contact beds necessary at intervals of three or four years. Either of these methods would prove extremely costly for so large a city as Boston.

In regard to trickling beds, our experiments have not yet been carried far enough to get definite results. With that particular process it is necessary to work on a large scale and out of doors; so during the past summer we have constructed an out-of-door trickling filter, which will take 10,000 gallons of sewage in the twenty-four hours at the rate of 2,000,000 gallons per acre per day. The English results have shown, as I have already said, that the trickling filter can treat sewage at much higher rates than other processes, giving a very satisfactory effluent, and that the body of the beds is cheaper to construct. On the other hand, the difficulties are two — the distribution of the sewage and the possible bad effect on the beds of the severe winter climate in this country. The question of distribution is a very serious one. In Columbus they use a system of buried pipes, with sprinkler heads at intervals to spray the sewage over the beds. In our filter the sewage drops from a wooden trough into metal cups, and splashes from them over the bed. This, we think, is simpler than any other device in use, and we hope will not be as seriously affected as some others by the climate. At present, engineers need to develop a cheap and practical system of distribution, and need more light as to the effect of a severe winter climate on trickling beds with various types of distributers. If those two problems can be solved it seems that the trickling filter furnishes the best treatment of sewage known. If it is necessary to produce the very highest purification, the turbid effluent from this type of bed may be settled and sterilized by copper or some other process, or may be strained rapidly through sand. In that way it is perfectly easy to make a bright, clear effluent at no very high cost. The trickling bed appears to be the ideal method

for solving the essential problem of sewage disposal, the oxidation of organic matter. It exhibits the simplicity of all scientific applications, which are merely intelligent intensifications of natural processes. A pile of stones on which bacterial growth may gather and a regulated supply of sewage are the only desiderata. We meet the conditions resulting from an abnormal aggregation of human life in the city by setting up a second city of microbes. The dangerous organic waste material produced in the city of human habitations is carried out to the city of microbes on their hills of rock, and we rely on them to turn it over into a harmless mineral form.

THE CRUISER[1]

By COMMANDER WILLIAM HOVGAARD, Royal Danish Navy

Introductory

The following discussion may be considered a continuation of my paper on "The Sea-Going Battleship," which I had the honor to read before this Society last year.[2]

Since then the great naval battle by Tsushima has taken place, and although the details of this battle are imperfectly known, several valuable facts stand out clearly.

Perhaps the most important experience is that long-range fighting is possible to an extent not anticipated before the war, a direct consequence of which is an enhanced value of heavy guns as compared with guns of semi-heavy or medium calibers. This corroborates the opinion expressed in last year's paper, that the caliber of secondary guns should be chosen as near to that of the heavy guns as due regard to its characteristic features will permit. Guns of 9.2-inch or 10-inch caliber were then recommended, and it seems likely that the war experience will tend to hasten the development in this direction.

Another consequence of long-range fighting is that the assumed average fighting distance, on which armor protection should be based, may be chosen greater than before, and that consequently armor thicknesses may on the whole be somewhat reduced. The average fighting range, assumed to be 3,500 yards in last year's paper, may probably be increased to 4,500 yards, which would permit a reduction in armor thickness on the battleship of about 1 inch K. C. On the other hand, ships have been struck below the armor belt in several instances, and the armor weight saved by reducing the thickness should, therefore, partly be used to extend the depth of side armor below the water line. The inner lateral coal bunker bulkhead might also with advantage be strengthened as protection against torpedo explosions.

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[1] Read at the thirteenth general meeting of the Society of Naval Architects and Marine Engineers, held in New York, November 16 and 17, 1905, and reprinted from the Transactions. Copyrighted by the Society.

[2] Reprinted in the Technology Quarterly, 18, pp. 257–288.

On the whole, the war experiences, as far as known, have borne out the conclusions arrived at in last year's paper. The overwhelming importance of guns compared with torpedoes as armament for large ships has been proved; the value of a complete system of armor protection, of rational and efficient water-tight subdivision, and of great initial stiffness have all been emphasized. (The *Osljabja* is reported to have capsized after having received the second shot wound in the water line.) The opinion that large size is necessary for a sea-going battleship has been confirmed.

In passing from the sea-going battleship to the cruiser, the general principles explained and stated in last year's paper will apply with but few modifications to the cruiser. As an introduction some of those principles will here be stated, and, where needed, their applicability to cruisers will be discussed.

1. The design should in every respect be based on *probable average conditions*.

2. *The large ship* may, due to greater load-carrying capacity, be made superior to the smaller in speed, gun power, and protection; but, moreover, it is inherently superior in point of nautical qualities, water-tight subdivision, economy of propulsion, and in the relation of sea speed to trial speed. These qualities are not subject to addition, and cannot, therefore, be compensated for by a greater number of units.

3. The *armor protection* should be "corresponding" to the armament, *i.e.*, it should be such as will enable the cruiser to keep up a long-continued fight with an equally powerfully armed antagonist under average conditions of fighting.

This principle has in many cases not been followed in cruisers, and will probably be objected to by many. It is believed, however, that the arguments put forward in last year's paper, in the paragraph "Relation between Armament and Armor," will be found to apply to cruisers as well as to battleships, and, in fact, to all ships which carry artillery as the principal weapon.

Also, the *distribution of armor* should in all classes of cruisers be in accordance with the principles stated for the battleship:—

4. The armor protection should be proportional to the relative importance of the part to be protected.

5. The protection of the ship should take precedence over that of the guns.

In designing the location and extension of armor, we have even

in the smallest cruisers to meet conditions analogous to those in the battleship. The assumed average conditions may indeed be different in degree, but not in kind, and the parts to be protected are arranged in essentially the same way in the two classes of ship.

We must, therefore, arrive at a system of armor distribution in the cruisers practically identical with that in the battleship.

The question of *deck armor versus side armor* is treated in the Appendix. This treatment is an extension of that found in last year's paper and contains a more complete solution of the problem. It is found that, as far as armor piercing is concerned, deck armor and side armor stand about even in battleships, *i. e.*, a given weight of armor may as well be applied to the side as to the deck, while in cruisers deck armor is somewhat more favorably situated. But in all classes of ships side armor is more effective in keeping shell explosions and shrapnel out of the ships, and it protects not only the vitals, but also the buoyancy and stability. Hence we conclude, as for the battleships, that:—

6. The armor weight should be chiefly applied to the sides, and no more weight should be given to the armor deck than necessary to its functions as a splinter deck.

The great divergency which we find in the design of cruisers is largely due to disagreement on the principles of protection. While these principles, as stated above, are now fairly followed in all recent large cruisers, this is far from being the case in cruisers of the smaller types.

It is argued by many that *small, fast cruisers* are not real fighting ships, and that they need not, therefore, be given a complete system of protection; that their best protection lies in a powerful battery by which they are able to deal a crushing blow to an adversary before he has had time to reply effectively (Elswick cruisers). On the basis of these arguments the so-called "protected" cruiser type, with only deck armor and a relatively heavy battery, has been retained for smaller ships, with few and quite recent exceptions. The water line and the upper works have received no protection, and guns even of large caliber (up to 10 inches) have been given only a light shield or no protection at all.

The insufficiency of this system was evident in the *Variag* at Chemulpo, where the sides were pierced in a number of places, and the ship took a heavy list. No shields were fitted to the guns, the crews of which were repeatedly swept away by shell fire; the complete absence of gun protection is said to have been extremely demoralizing to the men.

If a ship with numerous poorly protected guns and no water line protection falls in with a vessel of similar design, it will depend on skill or on mere chance which of the two adversaries is first destroyed, since an effective shot at the beginning of the fight is likely to determine the issue.

Such a design is, therefore, not based on average circumstances, but on superior skill or on mere luck. How mistaken we may be, one way or the other, as to the qualities of the *personnel* will be admitted, and the designer should, therefore, always consider these qualities as well as the chances of war to be even.

Cruisers of the fast, small type will not in the performance of their principal duties need guns of large caliber, since the only enemies which they ought to fight are all lightly protected or unprotected; but they do need some protection in order to fight such enemies, namely, that "corresponding" to the guns. If the system of protection is to be complete, this claim will, of course, put an early limit to the caliber.

As to the number of guns, it is better to have a smaller number of properly protected guns than a larger number of unprotected guns.

The closed turret installation seems here, as in the large ships, to be the best, in view of the innumerable fragments from high explosive shell, against which shields are only an imperfect protection. In the Russo-Japanese War the men behind gun shields were often badly wounded in their feet from such fragments. Shields should, therefore, only be used for the lightest guns, and the question of mounting 4-inch and even 3-inch guns in turrets on board small ships should be seriously considered.

The system of *water-tight subdivision* recommended for the battleships can only be partly carried out in cruisers; the relatively smaller beam, and in most types also the smaller displacement, imposes limitations, but the same general plan should be followed. Centre line bulkheads should be avoided in cruisers still more than in battleships on account of the smaller metacentric height, and should be fitted only where necessary between engine rooms. Doors in the principal transverse bulkheads should be avoided.

Before entering upon a discussion of the type and design of cruisers which will be most suitable to existing conditions, a brief historical review will first be given, with a view of studying the relation between the development and the causes which have produced and governed it. Thereafter these causes, as they exist now, and especially the present

requirements of the service, will be analyzed, and we shall thus obtain what is believed to be the best possible guide for future development.

Historical Review

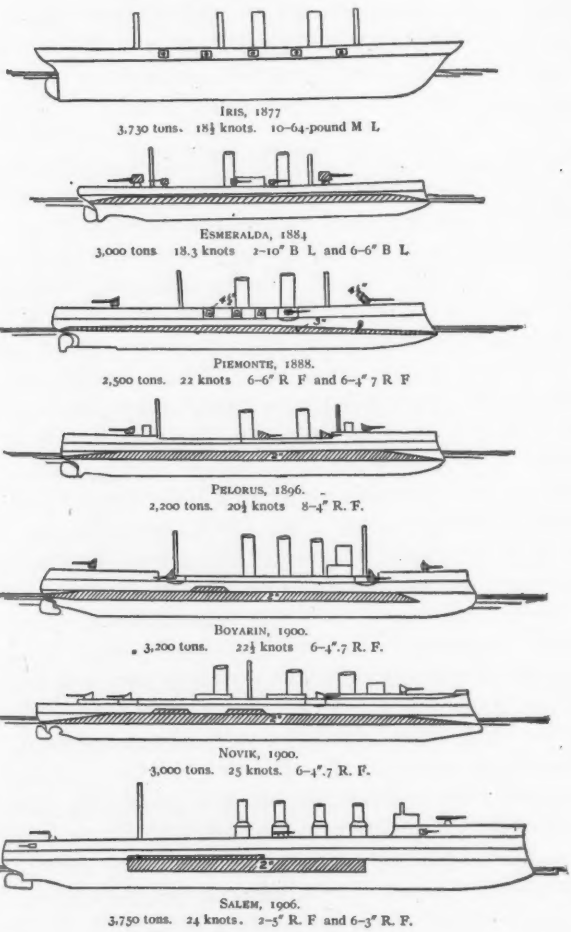
(See Plates 1, 2, and 3)

With few exceptions the development of the modern cruiser was, up till recent years, almost entirely governed by that of the English and French navies. The underlying policy has in these two countries generally been clearly defined or readily distinguishable, and the history of the cruiser, as far as a study of causes and effects is concerned, is, therefore, well represented by that of English and French cruisers, while reference to other navies need only be made in a few cases.

The original conception of a cruiser dates back to the days of sailing frigates: — light, fast vessels built for scouting, for attack on or protection of commerce, and for detached service.

After the introduction of steam the importance of this type seems to have been lost sight of to some extent, until the success as a commerce destroyer of the steam-propelled cruiser *Alabama* (1862) drew the attention of the world to this class of vessel. The immediate result was the creation of larger and more powerful types for the protection of commerce (*Wampanoag*, *Inconstant*, 1868). The armament of these ships was comparatively heavy, but they were entirely unprotected.

The differentiation in size which here originated has, broadly speaking, been maintained ever since, but near 1890 a further subdivision of the larger type took place, as explained hereafter. The smaller class was generally destined for commerce destroying, while some were built more especially for scouting and despatch service (*Iris*, 1878). The larger type was intended chiefly for protection of commerce, and also generally for service on distant stations; on account of the growing claim to protection it showed a tendency to increase in size. Already, at the end of the seventies, the "*protected*" *cruiser* was inaugurated by the *Comus* class (1878). The protected cruiser was characterized by having an armor deck and by the total absence of side armor, the buoyancy and stability being chiefly protected by a cellular subdivision in the region of the water line and by a belt of coal. In order to gain weight for the protective deck, the armament, and at first also the speed, was somewhat reduced; but by improvements in machinery, by the abandonment of sail power, and by a lighter hull construction the



IRIS, 1877
3,730 tons. 18½ knots. 10–64-pound M L

ESMERALDA, 1884
3,000 tons 18.3 knots 2–10″ B L and 6–6″ B L

PIEMONTE, 1888.
2,500 tons. 22 knots 6–6″ R F and 6–4″ 7 R F

PELORUS, 1896.
2,200 tons. 20½ knots 8–4″ R. F.

BOYARIN, 1900.
3,200 tons. 22½ knots 6–4″.7 R. F.

NOVIK, 1900.
3,000 tons. 25 knots. 6–4″.7 R. F.

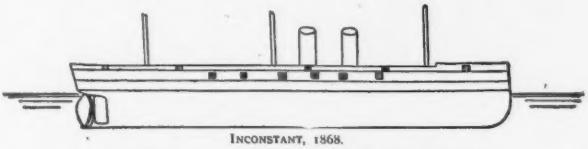
SALEM, 1906.
3,750 tons. 24 knots. 2–5″ R. F and 6–3″ R. F.

PLATE I. — SCOUTING CRUISERS
Scale 1″ = about 130 feet.

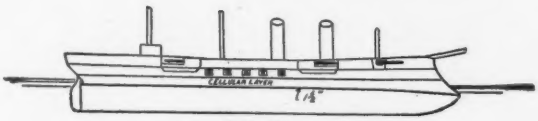
speed was soon raised even to the level of earlier despatch vessels. In the Elswick cruisers also a heavy armament was carried (*Esmeralda*, two 10-inch B. L. and six 6-inch B. L., 1884), but this was not done without sacrifice in seaworthiness (low freeboard) and in coal capacity.

From this period dates the idea of using cruisers against or as a substitute for ironclads, advocated in England by Lord Armstrong,

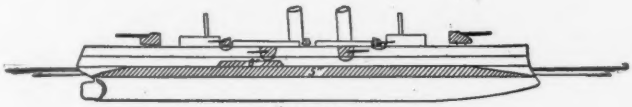
in France by Admiral Aube. At that time many armor-clads presented weak points in their unprotected ends (*Admiral* class) or in their large, unprotected superstructures (French ships), and this new idea, therefore, gained considerable influence and even caused a temporary pause to be made in armor-clad construction in most navies. In a few years, however, rapid firers, high explosive shell, and the introduction of powerful secondary batteries in armor-clads put an end to this notion, as far as protected cruisers were concerned.



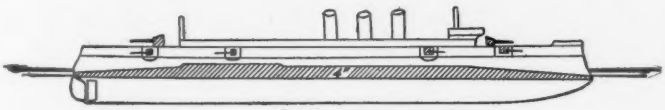
INCONSTANT, 1868.
5,780 tons. 16 knots. 10–12-ton M. L. and 6–6½-ton M. L.



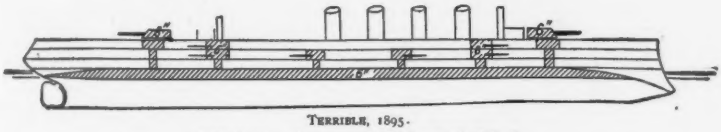
SFAX, 1884.
4,500 tons. 16 7 knots. 6–6".4 B. L and 10–5".6 B L.



EDGAR, 1890
7,350 tons 20 knots 2–9" 2 B L. and 10–6" R. F.



COLUMBIA, 1892.
7,400 tons 23 knots. 1–8" B L and 2–6" R F and 8–4" R. F.



TERRIBLE, 1895.
14,200 tons 22 knots 2–9" 2 B L. and 16–6" R. F.

PLATE 2.—LARGER UNPROTECTED AND PROTECTED CRUISERS
Scale 1" = about 130 feet.

The proper duties of protected cruisers were more clearly realized, and with the introduction of rapid firers smaller calibers of guns were used in these vessels (*Piemonte*, six 6-inch R. F. and six 4.7-inch R. F., 1888).

The larger class of cruisers was generally protected on the same principle as the smaller (*Mersey*, *Sfax*, *Chicago*, all from the middle of the eighties), but the progress in ordnance made it increasingly desirable to give a better protection to the water line. Hence a still larger type, the so-called *"armored" cruiser*, was gradually developed, characterized by the combination of deck armor with a more or less extended side protection.

The early armored cruisers were nothing but reduced copies of the battleships; the *Vauban* (1882) resembled the *Amiral Duperré*, the *Orlando* (1886) resembled the *Admiral* class. This seemed, indeed, perfectly logical, but in this way these cruisers came to share the defect of the armor-clads of that time — a too great concentration of armor.

The attempts made with armored cruisers had up till the end of the eighties been sporadic and not all of them successful; but from about 1890, after the construction of the French cruiser *Dupuy-de-Lôme*, dates the permanent introduction of the armored cruiser. In order to understand this step in the development and the subsequent rapid growth of the large cruiser, we must consider the peculiar and in some respects unique position of the two leading countries.

France considered herself at that time as the possible enemy of England and as her rival on the sea. The history of former wars, where French cruisers inflicted so much damage to British shipping, had not been forgotten in France. Now more than ever before was the sea-borne trade the vulnerable point of England, for on it depended the economic life and even the food supply of the country. France also felt it increasingly difficult to compete with England in the building of large armor-clads, and it was, therefore, natural that a policy of shipbuilding based on commerce destroying should find favor in France.

A number of small, very fast, protected cruisers and a few larger vessels of same type had already been built or were under construction, with the main object of eventually preying upon British commerce in distant seas (*Tage*, 7,600 tons, 1886; *Cécille*, 5,900 tons, 1888).

It was, however, soon realized by the French that these large vessels,

with their extensive unprotected sides, were too vulnerable in view of the widespread and violent effect of rapid firers and high explosive shell. Experiments on the effect of high explosive shell with *La Belliqueuse* fully confirmed this opinion, and showed the necessity of giving a much more extensive armor protection to the sides than had been given in the early armored cruisers. On the other hand, the thickness of armor would only need to be moderate (4 inches).

These considerations led to the construction of *Dupuy-de-Lôme* (6,500 tons, 1890), which, besides an armor deck, had the sides completely covered by armor up to the upper deck, and which was, moreover, a fast and well-gunned ship (heavy guns 7.6 inches).

During the nineties France built several cruisers of the *Dupuy-de-Lôme* type. The extension of armor was somewhat reduced, and, since at the same time the armor of the battleships was extended more and more up the side, we find that at the end of the decade the distribution of armor on the French cruiser was essentially the same as that on the French battleship. Also the guns were similarly disposed and protected in the two classes. At the same time, however, large protected cruisers also were constructed in France, such as the commerce destroyer *Guischen* (8,000 tons, 1897).

The *Dupuy-de-Lôme* found many admirers; not only did it seem well adapted to commerce destroying in distant seas, but it also caused a revival of the idea of substituting cruisers for battleships. Admiral Fournier advocated for this purpose an enlarged *Dupuy-de-Lôme*, and at the end of the decade a great step in size was taken by the construction of the first-class cruiser *Jeanne d'Arc* (11,300 tons, 1899). This ship was well suited to meet the large protected cruisers built by England in this period, but it was, in spite of its great size, entirely unfit for fighting battleships, for which purpose both its armament and protection were insufficient.

England, on the other hand, in view of the strong development of the cruiser in France and elsewhere, realized the necessity of making special efforts for the protection of her commerce. To every type of cruiser built in other countries, and especially in France and Russia, England replied with the construction of another type which was thought more powerful. Thus the *Dupuy-de-Lôme* was followed in England by the *Blake* and *Blenheim* (9,000 tons, 1890–91) and the *Edgar* class (7,350 tons, 1890), all of the protected type. Thus arose the subdivision of the large cruiser class referred to above, and hence-

forth we have at least three classes — first, second, and third — of which again the first and second are divided into protected and armored cruisers.

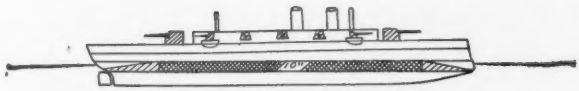
The English persisted through the nineties in the construction of cruisers of the protected type. In all classes size was increased in order to gain endurance, seaworthiness, and speed without reduction in military power, and a fleet of nearly eighty protected cruisers, largely of intermediate sizes, was constructed in this decade, ranging in displacement from 2,000 to 14,000 tons. The largest type was the *Terrible* (14,200 tons, 1895), built as a reply to the Russian armored cruisers *Rurik* and *Rossia*.

The idea was to use large cruisers for protection of commerce by patrolling the open ocean; second-class cruisers should be used for patrolling and eventually for convoying merchant ships in home waters; and the third class should be used chiefly as lookout ships. For the further protection of commerce, old armor-clads of reduced fighting value were to be used as convoys for merchant vessels in the East; they were, therefore, classed as armored "cruisers," but this term must here be considered a misnomer, since they had nothing in common with cruisers, except that they were used for what was usually considered cruiser service. Many of the English cruisers carried 9.2-inch guns, and were in this respect more powerful than the French; but on the other hand, their unprotected sides made them entirely unfit for standing modern shell fire. Bearing in mind the standpoint of ordnance at the end of the decade, it is probably not too much to say that *the protected cruiser had by the year 1900 become an obsolete type.* Even the largest of this class of vessel was exposed to destruction by the guns of medium caliber with which both cruisers and battleships were provided.

About that time the English finally abandoned the protected type of cruiser for all larger sizes, and adopted an armored cruiser type which in arrangement of guns and armor was very similar to the English battleship. Both hull and gun bases received a better protection than in the protected cruiser.

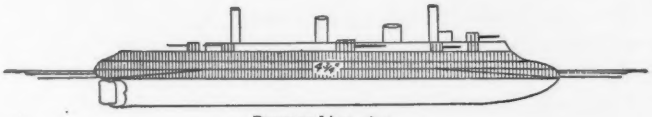
With characteristic energy England has in the few years since that time more than regained the lost ground by constructing a fleet of nearly forty powerful armored cruisers, ranging in displacement from 10,000 to 15,000 tons.

In the same period France has built a number of large cruisers of improved *Jeanne d'Arc* type.



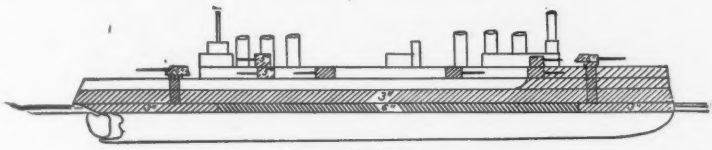
ORLANDO, 1886.

5,600 tons. 18 knots 2–9″.2 B. L. and 10–6″ B. L.



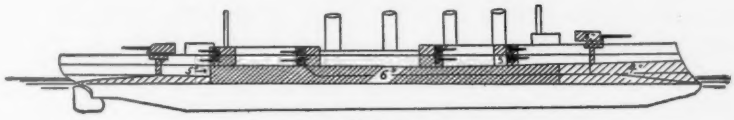
DUPUY-DE-LÔME, 1890.

6,500 tons. 20 knots. 2–7″.6 R. F. and 6–6″.4 R. F.



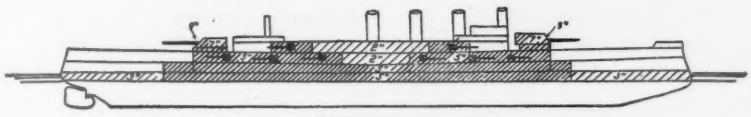
JEANNE D'ARC, 1899.

11,300 tons 22 knots 2–7″.6 R. F. and 14–5″.5 R. F.



DRAKE, 1901.

14,100 tons 24 knots 2–9″.2 B. L. and 16–6″ R. F.



TENNESSEE, 1904.

14,500 tons. 22 knots 4–10″ B. L. and 16–6″ R. F.

PLATE 3. — ARMORED CRUISERS
Scale 1″ = about 130 feet.

In both countries the development of the armored cruiser since 1900 has been characterized by a rapid increase in gun caliber and by the distribution of guns and armor on a plan closely resembling that of the battleships in the respective countries.

The armament is sufficiently powerful to inflict serious damage to battleships outside their heavy armor, and the protection is sufficient against guns of medium caliber, but for fighting heavy armor and heavy guns these ships are too weak.

The speed has been kept some 20 to 25 per cent. higher than that of the battleships.

In the United States the development in this period has taken the same course. The *Charleston* class (9,700 tons, 1903) is, for its size, weakly protected and gunned (6 inches), and does not indeed differ much from the protected cruiser, with which it is actually ranked; the *Pennsylvania* (13,680 tons, 1903) class is in both respects better provided, but the armored area is restricted and the caliber of the heavy guns (8 inches) is small for a ship of so great displacement. The *Tennessee* class (14,500 tons, 1905) marks a great improvement, carrying heavy armor-piercing guns (10 inches) and having a rational system of protection. The approach to the battleship type as regards arrangement of armor and guns has here, as in the English and French cruisers, been completed, the difference between large cruisers and battleships being now in all navies only one of degree.

The fighting capacity of the armored cruiser has reached a point which renders its participation in future fleet actions almost a certainty. We have already seen armored cruisers so used with great success at Tsushima, where some of them even went in line with the battleships. This contingency cannot fail to produce a further increase in military strength of these vessels, and has probably already contributed to the marked advance in this respect which has recently taken place.

Since the year 1900 the construction of intermediate sizes of cruisers (second class), such as were built so profusely and in such great variety in the nineties, has almost ceased in the leading navies.

It remains to describe the development of the third-class cruiser, and to show how the modern "*scout*" type evolved.

Small, fast cruisers, of displacements between 2,000 and 4,000 tons and of increasing speed, continued to be built during the nineties as before that time (*Cincinnati*, nineteen knots, 1892; *Galilée* and *Pelorus*, twenty to twenty-one knots, 1896; *Bojarin*, twenty-two and one-half knots, 1900). The ships of this period carry a relatively heavy armament and protection, the high speed having been attained by cutting down weight of hull and machinery (boilers). The speed is, however, inferior to that of many large cruisers (*Drake* and *County* classes, twenty-three knots), especially in a seaway, and this type, although very useful, can therefore not be entrusted with scouting at great distances from a base. Thus arose the claim for a still faster type, the *ocean scout*, inaugurated by the *Novik* (3,000 tons, twenty-five

knots, 1900). The high speed reached in that ship was obtained by an exceedingly light hull construction and low freeboard, by small weight of machinery (Thornycroft boilers) and small coal supply, while the battery was rather heavy (six 4.7-inch guns). In later types weight has been saved by reducing the gun power, as in the *Pathfinder* class (3,000 tons, ten 3-inch guns, twenty-five knots) and the *Salem* class (4,000 tons, two 5-inch and six 3-inch guns, twenty-four knots). The former type has very low freeboard and small coal supply; the latter has high freeboard and larger coal supply. The somewhat lower trial speed in the *Salem* class will probably be more than offset by its better sea-going qualities and relatively higher sea speed, but compared with recent armored cruisers the speed of the *Salem* class is still too low. Only by a further increase in displacement does it seem possible to obtain a type which combines sufficient speed with great endurance and seaworthiness.

Side armor is here used for the first time in third-class cruisers, but only as a belt of very limited extension.

SYNOPSIS OF HISTORICAL REVIEW

Summing up the various causes which have been operative in the development, we find first a *natural tendency to growth* in size in accordance with the principle stated at the beginning of this paper; and secondly, a development due to general *technical progress*. Both of these causes are still active and may be expected to produce in future the same tendency to increase in size and progress in quality that has characterized the past.

The controlling factor in the determination of types, and also largely in the development within each type, has, however, been *the requirements of the service;* but the teachings of history are here, on account of the peculiar strategical and economical condition of the leading countries, not of general application, and conclusions can therefore only be drawn with great discrimination.

As is evident from the brief historical review, the importance of the purely military duties incumbent on cruisers has in England and France been overshadowed by the attention which has been given to protection of and attack on merchant vessels. Chiefly on basis of this service, types have been determined, and the example of the leading navies has generally been followed by other navies, in many cases rather indiscriminately.

Expediency and opportunism have also played a great part in the

development, such as must indeed always be the case. Thus there has always been a tendency to meet each new class of vessel created by a rival navy with another still more powerful. This tendency has, for instance, been very marked in the English navy.

General Remarks on Choice of Types

Since, on the whole, the tactical and strategical duties, on which, ultimately, the issue of campaigns depends, have received but secondary attention in the past by the determination of cruiser types, we cannot expect that the existing types should be the best for such service. Even granting that they are necessary for countries for whom war on commerce, whether offensive or defensive, is an all-important consideration, it seems improbable that they should be the best general types, even for such countries. For other countries, such as, for instance, the United States, for whom war on commerce is unimportant, it is likely that types chosen directly or indirectly on basis of such warfare will be more or less unsuitable.

We cannot, therefore, in this matter safely go by precedent, but must study the question of types on independent grounds, by first considering *all* the duties which cruisers will have to perform and by assigning to each kind of duty its proper weight, according to the needs of the country.

Since control of the sea must always be the ultimate object of naval warfare, and since this can only be attained by defeating or effectively blockading the enemy's main force, *the consideration of the purely military duties should in all navies take precedence over those relating to commerce protection and destroying, etc.* On this principle the types should be chosen, and we shall, therefore, in the following commence the discussion with a study of types suitable for the former service, and thereafter examine whether and to what extent it will be necessary to create special types for the performance of the latter service.

In land warfare small bodies of cavalry may one day act as independent patrols or scouts and the next day they may form an integral part of a regiment, but in naval warfare no such integration of the units can be effected; no number of small cruisers can, by acting together, become the equivalent of a large cruiser. Each type has its limitations in use, and the more so the smaller it is; once we have created a type we have to accept its shortcomings.

Large ships are, on the other hand, better adapted for performing the duties of somewhat smaller ships than conversely. Hence we are led to prefer a larger type to the intermediate types, which, although suitable for some particular service, are unsuitable for other and, as we shall see, more important service which they may be called upon to perform.

Since, however, small ships cannot be dispensed with for service where small dimensions and great number are primary requirements, *we arrive at two main groups of cruisers, large and small.* Within these groups the number of types should be the smallest possible consistent with the requirements of the service, and ***ships of intermediate sizes should only be constructed when absolutely necessary.***

The conception of a cruiser is inseparably connected with the idea of speed; ***speed as a prominent quality is common to all sizes and types of cruisers.***

If, therefore, we would define the duties of this class of vessels we must examine what service does in particular require high speed for its performance, *i. e.*, speaking generally, a speed higher than that of the battleships.

A. Cruisers for Tactical and Strategical Service

For the sake of clearness, large and small cruisers will be discussed separately.

1. Large Cruisers

The service for which large cruisers are required may be defined as follows: —

(*a*) *Rapid Concentrations and Enveloping Movements during Fleet Action. Pursuit of a Retreating Enemy.* — For the performance of these tactical duties it must be of the greatest value to the commander of a fleet to possess ships endowed with higher speed than the main body of battleships. The importance of the element of speed in fleet action was shown in the use which Admiral Togo made of his armored cruisers in the battle of Tsushima.

In order, however, to derive full benefit of such faster ships they should be gunned and protected so as to meet the battleships on even terms, *i. e.*, they must themselves be battleships.

(*b*) *Support and Assistance of Smaller Cruisers.* — By scouting, safety service, and blockade of military ports smaller cruisers are detached to advanced positions, and will here need the support and assistance of more powerful ships, behind which they may seek shelter if needed, and which will generally assist them by taking an active part in their service.

Such supporting ships will need high speed in order to avoid being cut off by the enemy's battleships. High speed will also enable them eventually to chase the enemy's cruisers, and will be generally useful in the service here described. The fighting power should not be less than that of armored cruisers.

(*c*) *Reconnaissance in Force.* — When a battle is imminent it is often of the greatest importance to ascertain the strength and position of the enemy (Rojestvensky and Togo). This information cannot always be obtained without breaking through a screen of light and possibly armored cruisers, and such reconnaissance requires for its performance ships of high speed and great fighting power.

(*d*) *Independent Expeditions.* — Frequently it is required on short notice to send ships out to distant stations, as in case of military demonstrations or operations of smaller magnitude. Often considerable fighting power is required in order to meet all possible contingencies. Also, high speed and great endurance are here needed.

CHOICE OF TYPE

Comparing the relative importance of the duties assigned to large cruisers, it will probably be admitted that the tactical duties in fleet actions must be ranked above duties pertaining to reconnoitring, not to speak of the incidental service which in times of peace and war may be entrusted to cruisers.

A great naval power must therefore, first of all, possess cruisers that are perfectly suited to the former service, and it has already been stated that such vessels should simply be fast battleships. A reduction in gun caliber and in protection, as found in the ordinary armored cruiser, would make the type essentially inferior to the battleship. A reduction in number of heavy guns, retaining the caliber the same as in the battleship (*Vittorio Emmanuele*), seems irrational, since the saving in weight hereby attained will only be small if the protection is not to be sacrificed also.

But if armament and protection are to be exactly the same as in the

battleship, and if, in addition, the speed is to be higher, it is clear that, other features being equal, the displacement must be greater. Thus we arrive at a new type, an enlarged and fast battleship, which in the following will be referred to as the *battleship-cruiser.*

The battleship-cruiser will, compared with the armored cruiser of today, possess all the advantages inherent in the larger ship, as stated above, and will possess the fighting capacity of a battleship.

The sea speed, if not the trial speed, may probably, without undue increase in displacement, be made as great as that of the armored cruiser, taking sea speed to mean the highest speed sustained for a considerable time under average conditions of wind and sea.

If a fleet of battleships is accompanied by a squadron of battleship-cruisers the element of high speed seems to be sufficiently provided for, and it will be unnecessary to give the ordinary battleship more than what may at any period be considered a moderate speed (at present about eighteen knots). Thus the displacement of ordinary battleships and their cost may be kept within reasonable limits.

The other duties assigned to large cruisers under *b*, *c*, and *d* would not necessarily demand for their performance ships of so great power as the battleship-cruiser, the ordinary armored cruiser would be sufficient; but, as mentioned above, such vessels will unavoidably be forced also to take part in fleet actions, and for this service they are too weakly gunned and protected. It may be argued that the Japanese armored cruisers did excellent service in the battle of Tsushima, but this battle cannot be considered a reliable test of the type, because the better gun practice of the Japanese outweighed even great differences in *matériel.*

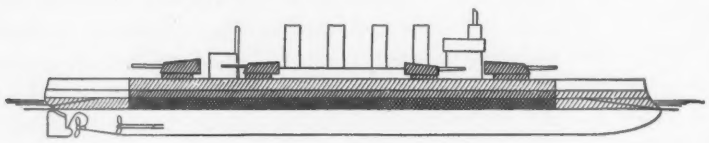
The first-class armored cruiser, as it is today, although a vast improvement on what it was only a few years ago, is still only partly suited for the duties which it may be called upon to perform, and cannot, therefore, be considered a fully satisfactory type.

On the other hand, the battleship-cruiser is not only the best cruiser type in fleet action, but is also eminently adapted for all other duties incumbent on large cruisers. If used as support for an advanced line of smaller cruisers it is able to hold its position longer than the ordinary armored cruiser, and is better able to stay the advance of hostile cruisers. A reconnaissance involving a violent penetration through the outer lines of the enemy can be performed with greater impunity by this type. Finally, the battleship-cruiser can, more safely than any

other type, be entrusted with independent expeditions to distant stations, as, indeed, with any detached service.

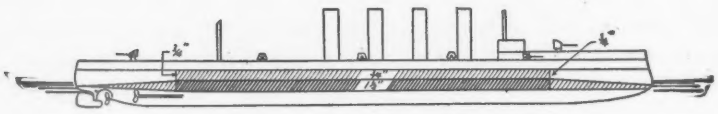
The only serious objection to this new type appears to be its great cost and the consequent small number of units that can be built for a given expenditure, but consideration will show that for the most important of the military duties stated above it is concentration of power, and not a great number of units, that is wanted.

Hence it is concluded that, at least *for all strictly military service, the armored cruiser should be abandoned, and a new, more powerful type, the battleship-cruiser, put in its stead.*



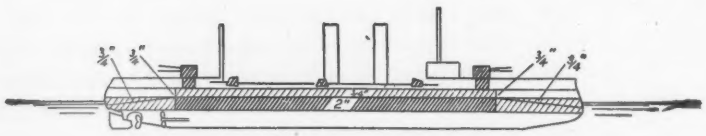
BATTLESHIP-CRUISER

Displacement: about 29,000 tons. Speed: 21 knots. Armament and Protection [same as in battleships, armament here assumed: 4–12″ and 8–10″ guns].



SCOUT

Displacement: about 5,000 tons. Speed: 25 knots. Armament: 10–4″.



CRUISER FOR SAFETY SERVICE, ETC

Displacement: about 3,000 tons. Speed: 20 knots. Armament: 4–5″ and 6–3″.

PLATE 4.— DIAGRAMMATIC SKETCHES OF PROPOSED CRUISER TYPES
Scale 1″ = about 130 feet.

GENERAL FEATURES OF THE BATTLESHIP–CRUISER

The general features of this type can only be determined relative to the type of battleship as it exists at any given time. It may be derived from the battleship as a somewhat finer vessel with a greater ratio of length to beam, and with a power sufficient to drive it at some 15 to 20 per cent. higher speed, but with same battery and same thickness and distribution of armor.

What this battery should be and how the armor should be distributed have already been discussed in last year's paper. In the accompanying diagram (Plate 4) the armament is supposed to be 4.12-inch and 8.10-inch guns.

If we assume the ordinary battleship to be of some 17,000 tons displacement and eighteen knots speed, the speed of the battleship-cruiser should be about twenty-one knots, which would probably require a displacement of about 20,000 tons, other features being equal.

An increase in speed could, of course, be obtained by higher forcing of machinery or by reduction in hull weight, but this does not seem justifiable in the battleship-cruiser any more than in the battleship.

An increase in speed attained by improvements in machinery (turbines, liquid fuel, etc.) would benefit both types alike, and would, therefore, not affect the position of the battleship-cruiser relative to the ordinary battleship.

2. Small Cruisers

The service for which small cruisers are required may be defined as follows:—

(*a*) *Reconnoitring or Scouting*, whereby vessels are sent out in direction of the enemy until contact with him is gained. Once contact is obtained it is generally required to be kept, and the scouts should endeavor to approach the main fleet of the enemy so as to discover its position and ascertain its strength. Fighting should, as a general rule, be avoided, the principal duty being observation. Scouting may be tactical or strategical. By the former, communication is generally kept up with the main fleet by wireless telegraphy or other means, if necessary through intermediate posts. Such posts should preferably consist of heavier cruisers, corresponding to supporting squadrons in cavalry tactics.

For strategical reconnoitring independent scouting parties are often sent out so far from their base or from the main fleet that no communication can be kept up with it, but in such case the scouting squadrons should be accompanied by one or more heavier cruisers.

The type suitable for scouting must possess a sea speed sensibly higher than that of the armored cruiser; it must have great endurance and therefore large fuel capacity, and the machinery must not be too fragile. Seaworthiness should be such as to allow long-continued sea service without undue straining of ship or crew. The battery should be sufficiently powerful for fighting other scouts on even terms and for dealing effectively with all torpedo craft.

(*b*) *Safety Service*, which might also be called passive reconnoitring, is a strictly tactical service performed by a line or screen of vessels disposed like advanced guards or outposts in front of the main fleet at a moderate distance, and always in touch with it. The main fleet may be under way or at anchor. The duty of these vessels is to prevent an enemy from approaching unobserved and to drive back scouts or torpedo craft which try to break through the line. On the approach of a more powerful enemy they are supposed to withdraw until they receive assistance from supporting vessels in rear or from the main fleet.

To the same kind of service belongs also *observation of a blockaded enemy* (Port Arthur).

Safety service does not require so high speed or so great endurance as scouting; but these qualities, as well as seaworthiness, should be present in a measure which will enable such vessels to follow the battleship fleets under all circumstances. The armament should be distinctly superior to that of the scouts, the duty of these vessels being not only observation but also resistance.

(*c*) *Despatch Service*, carrying important despatches to or from the commander of a fleet, etc. For this service high speed is the essential requirement, and it may, therefore, generally be performed by scouts or by torpedo vessels.

(*d*) *Independent Service.* — For the same kind of detached service as mentioned for large cruisers, also smaller cruisers will frequently be useful both in time of peace and war. Under most circumstances the types used for scouting and safety service will also be suitable for this service.

THE SCOUT

The scout is, according to the above, characterized by very high speed, great endurance, and perfect sea-going qualities.

In settling the *speed*, it should be borne in mind that the trial speed taken by itself is only a very imperfect measure of a ship's cruising capability.

By cutting down hull weight and machinery weight, and by forcing the boilers, extreme trial speed may be attained, but it is clear that, if the ship and machinery are to stand the strain of long-continued sea service, there must be a limit in this respect beyond which we ought not to go. This limit can only be determined, in accordance with the claims stated above, by competitive endurance tests of long duration, undertaken in company with armored cruisers under what may fairly be considered average conditions of sea on the ocean. Under such conditions the scout should be able to escape from the armored cruisers, showing an appreciable excess in speed.

In the absence of such tests we must use the imperfect measure of a maximum trial speed on the mile, which at present should probably not be less than twenty-five knots.

Turbine machinery should be used. Since the usefulness and safety of this class of ship depend as much on *the endurance* as on the speed, it is essential that it should be given a great fuel capacity. High speed is of little use if a limited supply of fuel forces a ship to go at a very reduced speed in order to reach its point of destination (*Novik*).

The fuel supply should be proportioned, not to the displacement, but to the power, and this ratio should not fall much below what it is in the armored cruisers.

A supply of liquid fuel for mixed combustion should be carried.

In last year's paper it was pointed out how size, length, and freeboard depend upon speed if good *nautical qualities* are to be secured; these remarks apply with equal force to the cruiser.

For maintenance in the long swell of the ocean of such high speeds as here required, the *length* of the scout should not be much less than that of its natural enemy, the armored cruiser (eventually the battleship-cruiser), *i.e.*, it should approach 500 feet.

Also the *freeboard* must be about equal to that of the armored cruisers, 16 to 18 feet amidships, giving two complete decks above the protective deck; and in order to permit still higher speeds than the armored cruiser, a low forecastle should be added.

Since many fast cruisers are now armed with 4-inch guns (*Hamburg*), and since this caliber is also well suited for fighting torpedo destroyers, a battery of 4-inch guns seems appropriate for ships of this class. An armament of two submerged torpedo tubes should be carried besides.

The *armor protection* should, in accordance with the principles stated at the beginning of this paper, be distributed as in the battleship, and should "correspond" to the gun caliber. The extent and thickness of armor are settled on basis of certain average conditions of fighting, which by way of illustration are here chosen as follows:—

Average fighting distance, 4,500 yards.

Average angle with beam at which projectile strikes the ship, 30°.

Average angle of fall to horizon, 5°.

Average angle of roll of ships, 8°.

If we are to protect the ship under these conditions against the fire from 4-inch guns, we arrive at a water line belt of $1\frac{1}{2}$-inch nickel steel extending all along the vitals, surmounted up to the gun deck by a strake of $\frac{3}{4}$ inch of the same material. Transverse protective bulkheads of $\frac{3}{4}$-inch thickness should be placed at extreme ends of ammunition rooms forward and aft. The splinter deck being of the usual sloping type would, if we take the coal protection into account, only need to be $\frac{1}{2}$ inch thick, both on slopes and top; the guns to be protected by 2-inch shields, or preferably mounted in twin turrets.

According to recent war experience, special attention should be given to the protection of the steering gear. Coal protection has shown itself to be very effective, and should be made full use of in the arrangement of bunkers along the sides.

By comparison with existing scouts it is found that, if the claims here stated are to be fulfilled, the proposed type must have a displacement of about 5,000 tons.

It does not appear necessary that ships of this class, even in a great navy, should be very numerous. For scouting, a few vessels well equipped for this service are to be preferred to a greater number of vessels more or less handicapped by their smaller size in point of sea speed, endurance, and sea-going qualities. It is not here as in safety service a question of covering a given line of observation, but of piercing such a line at one or a few points.

CRUISERS FOR SAFETY SERVICE

The type required for this service comes very near to the ordinary third-class cruiser possessed by all great navies.

The safety service will generally consist in patrolling a certain area or an arc round the main fleet at a distance which permits keeping touch with it. A trial speed of about twenty knots will probably be ample for the performance of this service, and this speed will also enable these vessels to follow a battleship fleet under all circumstances.

The ratio between fuel supply and horse power should not fall much below that in the battleships with which these cruisers are to operate.

Turbine machinery and liquid fuel for mixed combustion should be used.

There should be one complete deck above protective deck, with poop and forecastle; freeboard amidships about 10 feet.

The armament should consist of four 5-inch guns and a battery of 3-inch guns. The 5-inch guns will make these ships superior to most scouting cruisers. They should be mounted on poop and forecastle in twin turrets. Two submerged torpedo tubes should be carried.

The protection corresponding to the armament, under the same average conditions as assumed for the scout, would be: —

Water line belt, 2-inch nickel steel along vitals, $\frac{3}{4}$-inch beyond vitals.

Strake above belt up to main deck, $\frac{3}{4}$-inch nickel steel for length of vitals.

Protective deck, $\frac{3}{4}$-inch nickel steel all over.

Bulkheads at end of vitals, $\frac{3}{4}$-inch nickel steel.

Turrets, 3-inch armor.

The displacement of such ships would be about 3,000 tons.

Being powerfully armed and well protected for their size, these vessels will be formidable enemies for all scouts and lighter craft, and being well suited for many of the various duties which a navy has to perform outside of the tactical service, they will be of great general usefulness. In order to make the safety service effective a great number of patrolling vessels is required, and vessels of this class must, therefore, be much more numerous than those of the scout class.

B. Cruisers for Other than Tactical and Strategical Duties

The principal of these duties may be defined as follows: —

(*a*) *Protection of Merchant Shipping.* — When the military navy is much inferior to that of the enemy, protection of commerce is impossible. If it is of about even power or superior, but the enemy is

still unbeaten, and, even if blockaded, protection of commerce is very difficult to carry out, and is probably best effected by *convoys*, whereby large fleets of merchant vessels are gathered and accompanied by an escort of warships. Such convoying force must, however, in most cases consist not only of cruisers but also of battleships; and this method, whereby the naval forces are divided, and which is always attended with great risk, would, therefore, hardly be resorted to except in cases where such transport of goods is of vital importance to the country. (Convoy of food supplies from United States to France, 1794.)

Only after the naval power of the enemy is completely broken can there be question of an effective protection of commerce. The escape of cruisers from blockaded ports is, however, always possible, and if they find support, and notably facilities for coaling in their own stations or in the ports of a friendly Power, they may for a long time prey upon commerce. The best protection against such depredation is probably *patrolling cruisers:* on the ocean, large cruisers of great endurance, distributed for patrolling the important trade routes, and occasionally used as convoys; in narrow seas and near ports, where trade routes converge, more numerous but smaller vessels of less endurance, covering the whole of the threatened area. The former type must carry an armament enabling it to fight armored cruisers; the latter should be capable of driving off all light, fast cruisers.

(*b*) *Commerce Destroying.* — For commerce destroying on the ocean cruisers of high speed and great endurance are required; near a base smaller vessels with less endurance may be used. The speed should be sufficient to enable them to escape from larger cruisers. Since fighting with other warships should generally be avoided, the armament may be very light.

(*c*) *Blockading of Commercial Ports. Visitation and Search of Merchant Vessels.* — In order to catch blockade runners and to carry out visitation and search so as to prevent contraband of war being carried to the enemy's ports, ships of high speed and light armament are needed.

CHOICE OF TYPES

For *protection of shipping on the ocean* no better type could be conceived than the battleship-cruiser; its high, sustained speed and superior fighting power will make it a dreaded enemy for all other

classes of cruisers. Once the enemy's main fleet is beaten and driven in port, the battleship-cruisers may generally be spared for this service.

For *protection of shipping near ports*, whether at home or in the colonies, cruisers of intermediate size (second class) are appropriate. The seaworthiness and endurance, and hence the size, will depend on the nature of the seas in which they are to operate. The fighting power must depend somewhat on the position and nature of the station, but must always be sufficient to drive off all third-class cruisers. The protection should correspond to the armament, *i. e.*, the cruisers should be "armored." The displacement would, according to circumstances, be from 5,000 to 10,000 tons. Ships of these classes, which are not well suited for the purely military service, are hardly needed in large number by any other country than England, *i. e.*, under present conditions.

For *commerce destroying* on the ocean first-class armored cruisers are by many considered the best type, since their fighting power gives them great independence. It appears, however, that not until all hope of defeating the enemy's military navy has been abandoned would it be justifiable to detail such powerful ships for this service.

Since great dissemination and high speed of the attacking cruisers are the chief requirements, while fighting power is of small importance, the scout, such as proposed above, seems a more appropriate type for this service.

For attack on commerce in narrow seas, as well as for blockade and visitation service, the scouts and also such smaller cruisers as above proposed for safety service may be used.

Summary and Conclusions

We have seen from the historical review how the development of cruisers has been controlled largely by regard to war on commerce. It has been pointed out that the primary object of naval warfare is to break the naval military power of the opponent, in order thereby to obtain control of the ocean, since such control carries with it the attainment of all other desired objects, also control of commerce.

This latter object must, therefore, be secondary, as far as naval operations are concerned, even although it may in some cases be of vital and therefore primary importance to the country. The shipbuilding policy should follow the same lines, first providing cruisers suitable for military service, and, secondly, for commerce protection or commerce destroying.

A reversal of this order of precedence can only be made to the detriment of the general usefulness of a navy.

This policy, being based on fundamental strategical principles, should be followed by all countries.

For a country like the United States, which has little commerce on the ocean to protect, and to which the inconclusive and uncivilized method of warfare called commerce destroying is not likely to appeal, it appears that the shipbuilding policy should be directed exclusively towards purely military objects.

By an analysis of the duties which belong to cruisers in a war between military navies, it should be determined which of these duties are the most important, and on basis of these the proposed types of cruisers should be chosen. This is what has been done in the paper, with the result that a few types appear to be sufficient for all strictly military duties, viz. (see Plate 4):—

1. *Battleship-cruisers* of same military strength as ordinary battleships, but of higher speed (about 20,000 tons, twenty-one knots).

2. *Scouts* of extreme speed, great endurance, perfect sea-going capability, and light armament (about 5,000 tons, twenty-five knots).

3. *Small cruisers* of moderately high speed, fair endurance, relatively powerful armament and protection (about 3,000 tons, twenty knots).

The first two types are required only in small number, the last type in greater number.

The building of other special types, not perfectly suited to the primary service of a navy, implies reduced military strength and increased expenditure, and should be adopted only where absolutely necessary.

The present type of first-class cruiser (Tennessee, Minotaur, and Edgard Quinet), although useful in many cases, does not seem indispensable for any particular service, and is ill suited for its most important duty, participation in fleet actions, and it should, therefore, be abandoned.

Second-class cruisers appear to be useful or necessary only to those navies which, like the English, have a great ocean trade to protect.

For a navy like that of the United States it would, therefore, seem unnecessary and uneconomical to multiply cruiser types beyond the three here proposed.

APPENDIX

Comparison between Deck Armor and Side Armor

The treatment here given of this problem is an extension of that found in the Appendix of last year's paper on "The Sea-Going Battleship." It is more complete, giving the general solution under any direction of trajectory of projectile, and any angle of heel of the ship, and it is believed that by a judicious choice of the involved elements, so as fairly to represent average conditions, this treatment will enable us to form a tolerably correct idea of the relative value of deck armor and side armor as protection against armor piercing.

The deck is supposed to be of the sloping type with flat top, and in comparing the weight of deck armor with the weight of equivalent side armor, the sloping armor on each side is compared with a water line belt on each side, carried up to such a height as to shelter the slope under the assumed angle of heel, fall, etc. In case of the flat part of the deck, account must be taken of the fact that it offers protection against fire from both sides, being in this respect superior to side armor, which must always be duplicated in order to shelter a given section of the ship. As an equivalent of the flat part we must therefore reckon a strake of side armor on each side above the belt.

The knuckle lines of the protective deck are supposed to run parallel to the sides of the ship and nearly straight, an assumption which is very nearly correct for that part of the ship which contains the vitals.

The plane of trajectory is supposed to form an angle φ with the athwartships plane of the ship, and the angle of fall relative to a horizontal plane is α.

The ship heels over an angle β.

Let β' = angle between a horizontal line in the plane of trajectory and the flat deck.

This angle is found from the spherical triangle ADE (Fig 2):—

$$\sin \beta' = \cos \varphi \sin \beta. \qquad (1)$$

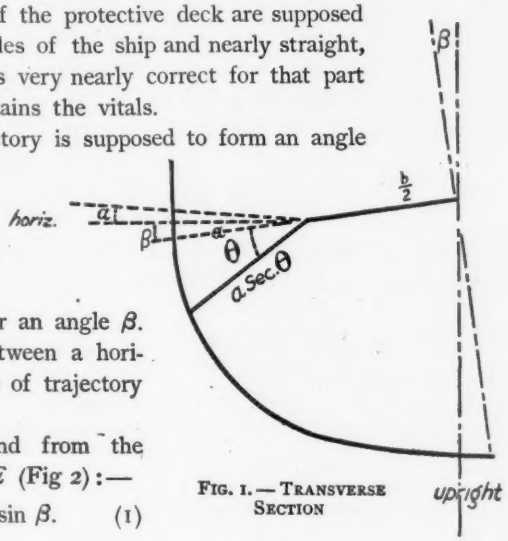


Fig. 1. — Transverse Section

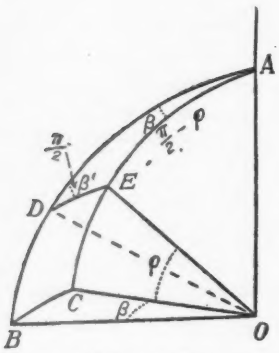


FIG. 2.—AOC IS A HORIZONTAL PLANE. AOB IS IN THE PLANE OF THE FLAT DECK

If ψ = angle at which flat deck is struck by projectile, we have, very approximately:—

$$\psi' = \beta' + a. \qquad (2)$$

Let θ = angle of slope of protective deck relative to flat part, and let $\theta + \beta = x$ and $x + a = \gamma$.

x' = angle between a horizontal line in plane of trajectory and sloping deck, is found from triangle AEG (Fig. 3):—

$$\sin x' = \cos \varphi \sin x. \qquad (3)$$

γ' = angle at which sloping deck is struck.

Then, very approximately:—

$$\gamma' = x' + a. \qquad (4)$$

Let φ' = angle at which side armor is struck, then from triangle MNP (Fig. 4), very approximately:—

$$\cos \varphi' = \cos \psi' \cos \varphi. \qquad (5)$$

To find height of side armor necessary to replace the armor deck, let (see Figures 1 and 5):—

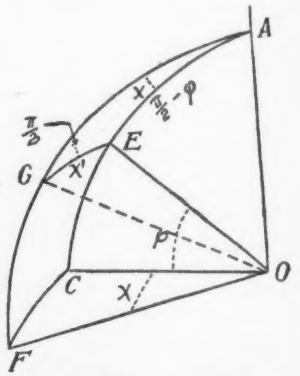


FIG. 3.—AOC IS IN A HORIZONTAL PLANE. AOF IS IN THE PLANE OF THE SLOPING DECK

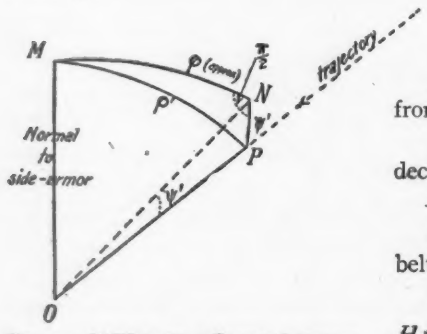


FIG. 4.—OMN IS IN A PLANE PARALLEL TO THE FLAT PART OF THE PROTECTIVE DECK

a = distance of knuckle line from ship's side.

b = breadth of flat part of deck.

H = height of belt.

h = height of strake above belt.

Then, very approximately:—

$$H = a\,[\tan \theta + \sec \varphi \tan \psi']. \qquad (6)$$

$$h = b \sec \varphi \tan \psi'. \qquad (7)$$

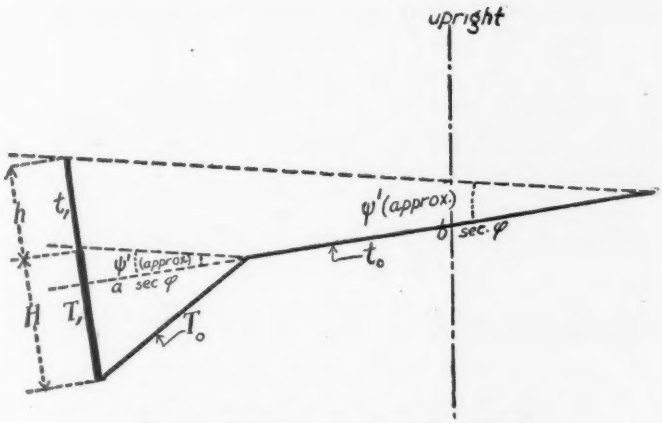


FIG. 5.—SECTION IN PLANE OF TRAJECTORY

We are now in position to estimate the weight of the different parts of armor.

COMPARISON BETWEEN SLOPE AND BELT

Let W_0 = weight of sloping armor on one side.
W_1 = weight of equivalent belt armor on one side.
T_0 = thickness of sloping armor.
T_1 = thickness of belt armor.

Since the side armor is subject to oblique impact it is equivalent to armor of a thickness T_1', which, up to angles of about 30°, may be connected with T_1 by the relation:—

$$T_1 = T_1' \cos \tfrac{1}{2}\varphi,$$

based on Tresidder's formula and on the assumption that for moderate angles of incidence the velocity normal to the plate required for perforation is constant.

Also, since T_1', by supposition, is to be the thickness equivalent to T_0 under the given conditions of impact, $T_1' = r\, T_0$ where r is a coefficient, found corresponding to the angle of impact γ' from a curve, given and described in last year's paper (TECHNOLOGY QUARTERLY, 18, page 282).

$$\therefore T_1 = r\, T_0 \cos \tfrac{1}{2}\varphi'.$$

Hence $W_1 = T_1 H = T_0 ar \cos \tfrac{1}{2}\varphi' \, [\tan \theta + \sec \varphi \tan \psi']$.

$W_0 = T_0 a \sec \theta$.

$$\therefore \frac{W_1}{W_0} = r \cos \theta \cos \tfrac{1}{2}\varphi' \, [\tan \theta + \sec \varphi \tan \psi'], \qquad (8)$$

which gives the desired relation between the weight of side armor and the equivalent armor on the slope.

Comparison between Flat-Deck Armor and Side Armor above Belt

Using the same suffixes as above, but small letters, we find:—

$$t_1 = t_1' \cos \tfrac{1}{2}\varphi'.$$
$$t_1' = t_0 r.$$
$$\therefore t_1 = t_0 r \cos \tfrac{1}{2}\varphi'.$$
$$w_1 = t_1 h = t_0 br \cos \tfrac{1}{2}\varphi' \sec \varphi \tan \psi'.$$
$$w_0 = t_0 b.$$
$$\therefore \frac{w_1}{w_2} = r \cos \tfrac{1}{2}\varphi' \sec \varphi \tan \psi'. \qquad (9)$$

In order to obtain an idea of what these formulæ really mean, we must work out numerical examples, and in doing so the different angles are chosen so as to correspond to what is believed will be average conditions of fighting and of rolling.

Assume:—

Angle between plane of trajectory and athwartships plane, $\varphi = 30°$.

Angle of roll $\beta = \begin{cases} \text{Battleship, } 5°. \\ \text{Cruiser, } 8°. \end{cases}$

Angle of fall $= \begin{cases} \text{Battleship, } 2°. \\ \text{Cruiser, } 5°. \end{cases}$

Angle of slope of armor deck, $\theta = 30°$.

1. Battleship or Battleship-Cruiser

We here find:—

$\beta = 5°$	$\beta' = 4° 20'$	$\theta = 30°$	$x = 35°$	$x' = 29° 48'$
$a = 2°$	$a = 2°$	$\beta = 5°$	$a = 2°$	$a = 2°$
$\psi = 7°$	$\psi' = 6° 20'$	$x = 35°$	$\gamma = 37°$	$\gamma' = 31° 48'$

$\varphi = 30°$, $\varphi' = 30° 35'$.

For the sloping deck, where the angle at which the deck is struck is:—

$$\gamma' = 31° 48',$$

we find from the curve (TECHNOLOGY QUARTERLY, **18**, page 282) that

$$r = 1.9.$$

For the flat deck we find, corresponding to

$$\psi' = 6° 20', r = 5.3;$$

and hence from (8), $W_1 = .927\ W_0$,
and from (9), $w_1 = .543\ w_0$.

Ordinarily the armor on the slopes is about twice as thick as on the flat deck, *i.e.*, $T_0 = 2\ t_0$, and, roughly, $b = 4\ a$.

$$\therefore\ W_0 = T_0\, a \sec\theta = \tfrac{1}{2}\, b t_0 \sec 30° = .577\ w_0.$$

Total weight of armor deck $= 2\ W_0 + w_0 = 2.15\ w_0$.
Total weight of side armor $= 2\,[W_1 + w_1] = 1.854\ W_0 + 1.086\ w_0$
$= 2.15\ w_0$,

which shows that under the assumed conditions the weight of protective deck armor in a battleship is the same as that of the equivalent side armor.

To the weight of side armor should, however, be added that of the armor bulkheads, which it is necessary to place at the end of the vitals in order to complete the protection by vertical armor. It is found that this addition is, in battleships, under the assumed conditions about 5 per cent. of the weight of the side armor.

2. SMALL CRUISERS

We find:—

$\beta = 8°$	$\beta' = 6° 55'$	$\theta = 30°$	$x = 38°$	$x' = 32° 15'$
$a = 5°$	$a = 5°$	$\beta = 8°$	$a = 5°$	$a = 5°$
$\psi = 13°$	$\psi' = 11° 55'$	$x = 38°$	$\gamma = 43°$	$\gamma' = 37° 15'$

$\varphi = 30°$, $\varphi' = 32° 5'$.

Corresponding to γ' we find for the sloping armor, $r = 1.7$.
Corresponding to ψ' we find for the flat armor, $r = 3.8$.
From (8), $W_1 = .943\ W_0$.
From (9), $w_1 = .723\ w_0$.
Assume $T_0 = 2\ t_0$ and $b = 2.5\ a$, then

$$W_0 = .924\ w_0.$$

$$\text{Total weight of armor deck} = 2\,W_0 + w_0 = 2.85\,w_0.$$
$$\text{Total weight of side armor} = 2\,[W_1 + w_1] = 1.886\,W_0 + 1.446\,w_0 = 3.19\,w_0.$$
$$\therefore \frac{\text{weight of side armor}}{\text{weight of deck armor}} = 1.12,$$

i. e., the equivalent side armor is. 12 per cent. heavier than the deck armor in a cruiser under the given assumptions. The addition which must be made for armor bulkheads is, in the cruiser, found to be about 3 per cent. of the side armor, bringing the total excess percentage for vertical armor up to about 15 per cent.

While, therefore, in battleships vertical armor and deck armor stand about equal, the deck armor shows in small cruisers an appreciable superiority, as far as armor piercing is concerned.

As stated in the paper, this superiority is, however, more than offset by the circumstance that deck armor does not prevent shell from entering the ship and exploding inside; it leaves the side liable to be torn open by high explosive shell, and does not protect the buoyancy and the stability to the extent that the same weight of side armor would do.

It is, therefore, concluded that *the greater part of the armor weight should be concentrated on the sides in all classes of warships, and no more weight be given to the armor deck than necessary to its function as a splinter deck.*

SUBMARINE SIGNALING

By HENRY R. GILSON

(Read November 9, 1905)

TWENTY years ago little was known about the transmission of sound under water, so little, in fact, that the inventors of the system had to commence at the beginning to demonstrate various principles in order to furnish a working basis. It was known that sound traveled through water at a velocity over four times as great as through the air. Practically nothing was known concerning the effects of temperature, currents, depth, etc., upon the sound wave. No experiments of value had been performed in *salt* water, little was known of the effect of salt water upon the different metals, nothing could be learned as to what sounds were the most far-reaching under water, and, although some few experiments had been performed with bells many years before, yet the proper proportions of the bell as a sound producer, such as the best pitch, weight, thickness of sound bow, weight of clapper, striking point, energy to be imparted to the clapper, method of suspension, etc., were a complete mystery. The inventors attacked the problem with great energy, and although many times discouraged at the results obtained they worked faithfully and consistently toward an end which to them must have seemed far distant.

In 1826 Colladon and Sturm made a series of experiments at Lake Geneva to determine the velocity of sound in water. They suspended a bell, weighing about 150 pounds, 5 feet under water from the side of a boat, and struck it with a hammer attached to the end of a lever. The lever was equipped with such mechanism that it ignited a handful of powder at the instant the hammer struck the bell. Stationed in another boat they listened for the bell sounds, propagated beneath the surface, which were conveyed from the water by a cylindrical tube of tin, one end of which terminated in an orifice for insertion in the ear, the other being spread out somewhat in the form of a spoon. With this simple apparatus, by placing the large end a few feet under water, Colladon was able to hear with perfect distinctness the blows of the

hammer on the bell across the widest part of Lake Geneva, when the calculated distance between the two boats was not less than eight miles. The sounds were as distinct and brief at eight miles as at one-eighth of a mile from the bell. One set of observations was made during a strong wind, the lake being violently agitated, and yet in spite of the noise of the waves which struck the receiving tube he took his observations with the same accuracy as when the air and water were still, and he says, "I am convinced, by employing a larger bell and improving and enlarging the hearing apparatus, that easy communication could be effected beneath the surface of the water up to forty or fifty miles."

It appears from subsequent experiments that temperature causes considerable variation in the rate of transmission even in fluids, though far less than in gases. In practice, however, this variation is negligible. Currents or tides also produce more or less variation in the velocity of the sound through the water. According to theory, but not yet proven by experiments, a sound should be heard in water farther against a surface current than with it, because the sound would travel slower on the surface against the current, and thus the lower sound waves would be refracted upward, extending the range. Conversely, sound traveling with a surface current should move faster on the surface than below, and would therefore bend downward, decreasing the range. A sound wave moving across a current would be refracted to the surface up stream and refracted to the bottom down stream. The angle at which the observer should be stationed in his relation to the source of the sound and the direction of the current, in order to get the sound as he would in still water (or, in other words, to escape a refraction), would depend upon the velocity of the current and the temperature, but it would always be more or less up stream. However, it is evident that whatever may be the velocity of the current, whatever its temperature or direction, the sound signal must be so powerful that it can be heard to a sufficient distance to warn mariners of their danger.

Sound signals in air constitute so large a factor of safety to the navigator that the scientists attached to the lighthouse establishments of the various countries have given much attention to their protection and perfection. The success of the United States has been such that other countries have sent commissioners here to study our system.

It has been demonstrated that any signal sounding in air cannot be considered reliable at all times, that there are variations of the atmosphere which decidedly affect the audibility of the signal, and

that a signal operating in a practically homogeneous medium is the only one upon which absolute reliance can be placed.

Among other erroneous notions is one which occasionally brings practical men, even shipmen, to grief. It is the idea that sound is always heard in all directions from its source, according to its intensity or force and according to the distance of the hearer from it. Instances of this fallacy have accumulated, and they are emphasized by shipwrecks caused by the insistence of mariners on the infallibility of their ears, which has made them accept, unquestioned, the guidance of sound signals during fog, as they have of lighthouses during clear weather. The fact is, audition is subject to aberrations, and under circumstances where least expected. We have learned by sad experience that implicit reliance on sound signals in air may (as it has) lead to danger, if not to death. The wreck of the steamer *Rhode Island* on Bonnet Point in Narragansett Bay, which happened in 1880, is only one of many. A million dollars in property was lost; and the wreck was caused, it was said, by the failure of the fog signal on Beaver Tail Point to sound at that time. As a matter of fact, investigation showed that the fog signal was in full operation when the wreck took place, but it also brought out the fact *that while there was no lack in the volume of the sound emitted by the signal, there was often a decided lack in the audition of that sound*, so much so that it would not be heard at the distance expected or at the place expected; that it could not be heard at all at some points, and then farther away it could be heard better than near by; that it could be heard and lost, again and again, all within reasonable earshot — and all this while the signal was in full blast and sounding continuously.

The lighthouse board has known from the first that aberrations in audibility might occur near any fog signal. Their publications show that Professor Henry, scientific adviser, had the subject for many years continuously under advisement, and that many experiments were made, and various reports on them submitted to the board, as to the use and value of its several kinds of fog signals. The signal is often heard at a great distance in one direction, while in another it will be scarcely audible at the distance of a mile. This is not the effect of the wind, as the signal is frequently heard much farther against the wind than with it. The most perplexing difficulty, however, arises from the fact that the signal often appears to be surrounded by a belt, varying in radius from one to one and one-half miles, from which the

sound appears to be entirely absent. Thus, in moving from a station the sound is audible to the distance of a mile, is then lost for about the same distance, after which it is again continuously heard for a long time. This action is common to all ear signals in air, and has been at times observed at all stations, at one of which the signal is situated on a bare rock twenty miles from the mainland, with no surrounding objects to affect the sound. Fog does not seem, so far as experience goes, to be a factor of any consequence whatever in the question of sound. Signals may be heard at great distances through the densest fog which may be entirely inaudible in the same direction and at the same distance in the clearest atmosphere. It is not meant by this statement that fog may assist the sound, as at another time the signal may be absolutely inaudible in a fog of like density where it had before been clearly heard. That fog has no great effect can easily be understood when it is known that even snow does not deaden sound, there being no condition of the atmosphere so favorable for the far-reaching of sound signals as is that of a heavy northeast snowstorm, due, supposedly, to the homogeneity produced by the falling snow. The worst conditions for hearing sounds seem to be found in the atmosphere of a clear, frosty morning, on which a warm sun has arisen and has been shining for two or three hours. If the law of these aberrations in audibility can be evolved and some method discovered for their correction, as the variation of the compass is corrected, then sound in air may be depended upon as a more definite and accurate aid to navigation.

It is at all times interesting to note the success of an American invention in the world's markets. Conspicuous in this line at present is the device for submarine signaling, which was invented several years ago, and which has since gone on attaining success, until now a number of transatlantic liners are equipped with the receiving apparatus and the eastern coast of Canada has been fitted out by the Dominion government with the signals. The first experiments along this line were made, as heretofore mentioned, by Colladon and Sturm on Lake Geneva early in the last century. These tests measured the speed of sound in fresh water, but made no other important contribution to the subject. For sixty years no attention seemed to have been paid to the matter. With the advent of the microphone and the speaking telephone, however, various inventors in England, notably Edmunds, Neale, Smallpage, and Lake, made serious theoretical excursions into

the subject. So far as is known, their work was wholly of a theoretical nature, their apparatus being entirely impracticable.

The same is true of the inventions made in Germany and France during the last thirty years, which were intended to solve the problem of sound transmission in water.

The main idea of all these inventors was to provide ships with means of hearing signals sent to them through the sea, or possibly to hear the breakers dashing against a rocky coast. Without exception, all relied upon some telephonic electrical apparatus to be attached to the outside of the vessel or to be lowered overboard into the water, while no one appears to have considered using the ship itself as a collector of sound.

Had any of these inventors made practical applications of their apparatus, they could not long have remained in ignorance of the value of the vessel itself as a factor in the problem.

Although the earliest attempts were made in England and Germany, the first student in physics to make any practical experiments was Professor Lucien I. Blake, now professor of physics in Kansas University, who, in 1883, while in Berlin investigating the experiments of Colladon and Sturm, conceived the idea of communicating between vessels at sea by means of submarine signals. For small craft he found that a pipe shaped much like a powderhorn, with a thin, flexible membrane stretched tightly across its broad end, made a successful receiver. With the small end made to fit the ear, and the diaphragm below the surface of the water, the sound of a hand bell nearly a mile distant had been received. It was necessary, however, owing to its cumbersomeness, to devise a better form of receiving apparatus. The ordinary telephone receiver and transmitter would not work under water. Various forms of microphonic transmitters were constructed, and experiments on Long Island Sound and on the Wabash River were conducted as opportunity permitted. His work attracted the attention of the Lighthouse Board, and facilities of every kind were extended him. In 1894, assisted by Mr. A. B. Johnson, the chief clerk of the board, and one who was familiar with all the vagaries of air signals, Mr. Blake made a long series of experiments at the Portsmouth (New Hampshire) Navy Yard. He established for the first time the important fact that sound in the water surrounding a ship would pass readily through its walls into the hold. One of the vessels used was the old frigate *Constitution*, and although her sides were 20 inches thick the

sound of oar blades struck together under water some distance away was distinctly heard by observers inside the ship.

The war between the United States and Spain stopped these experiments, but at the same time it stimulated a new student in the field — Mr. A. J. Mundy, of Boston — who shared in the anxiety regarding the Spanish torpedo boats, and conceived the idea that their approach might be heard through the water. This came to him through the recollection of having heard stones strike together under water when a boy.

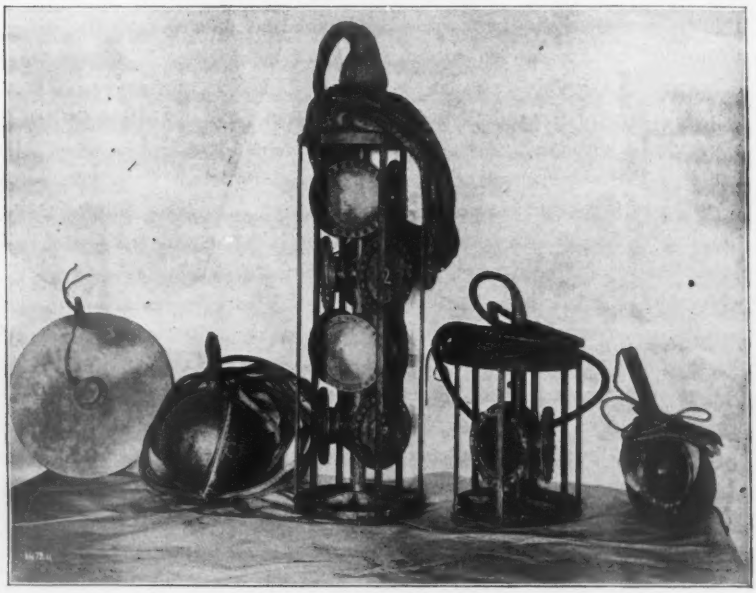


FIG. 1. — HOLLYHOCK TRANSMITTERS

Believing that a microphone might be used successfully in water, in 1898 he engaged the assistance of Professor Elisha Gray, of Chicago, and for four years they worked steadily on this problem. Innumerable experiments were made with various types of sound transmitters and submerged bells, and although it was soon ascertained by them that sound in water would easily pass through the walls of a vessel, as Professor Blake had shown, they became convinced that it was necessary to lower some kind of telephonic apparatus into the water. The largest and by far the most successful, as shown in Figure 1, weighed nearly 100 pounds. This was, of course, an impracticable kind of apparatus,

and was built with this knowledge in mind, but it served to prove certain facts relating to transmitters.

In 1902, as Professor Gray's endeavors were in the first stages of progression, he died, and the work was taken up by his co-worker, Mr. Mundy; but owing to failing health he was obliged to abandon the subject, and Mr. J. B. Millet, a well-known Boston business man who had heretofore taken deep interest in practically demonstrating the use of signals under water, took the guidance of the experimental ideas of Professor Gray and Mr. Mundy, and thrashed them out so as to make them practicable, adding certain ideas of his own. For four years, as vice-president and general manager of the Submarine Signal Company, he has given almost his whole time to constant improvement and experiment in the subject; and it is to him, for his tireless endeavors and for placing the system of submarine signaling upon a practical and commercial basis, that great credit is due.

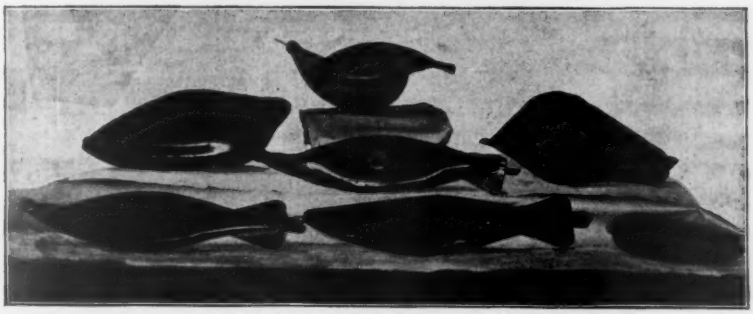


FIG. 2. — FISH TRANSMITTERS

Mr. Mundy's most important contribution was a device for placing sound transmitters inside a ship. In his laboratory experiments he discovered that if a tumbler filled with a solution was placed inside and against an empty iron kettle floating in a tank of water, the bell sound in the water of the tank could readily be taken out of the solution in the tumbler by means of a microphone immersed therein, although the same microphone, placed against the side of the kettle, collected very much less sound. The first actual application of these principles was so discouraging that the inventors were once more driven to design some form of apparatus to be towed overboard, for it was found that the ship's own noises filled the microphone with a roar and completely shut out all outside sounds. Accordingly, ingenious effort was bent

toward a device to be towed overboard by an insulated wire properly attached, with its terminal on shipboard communicating with the usual telephonic ear piece. Various fish-shaped models, shown in Figure 2, were all more or less successful in picking up bell sounds in the water when towed by a tug going eight knots; but, as none of the forms could be used to ascertain the direction from which the submarine sounds

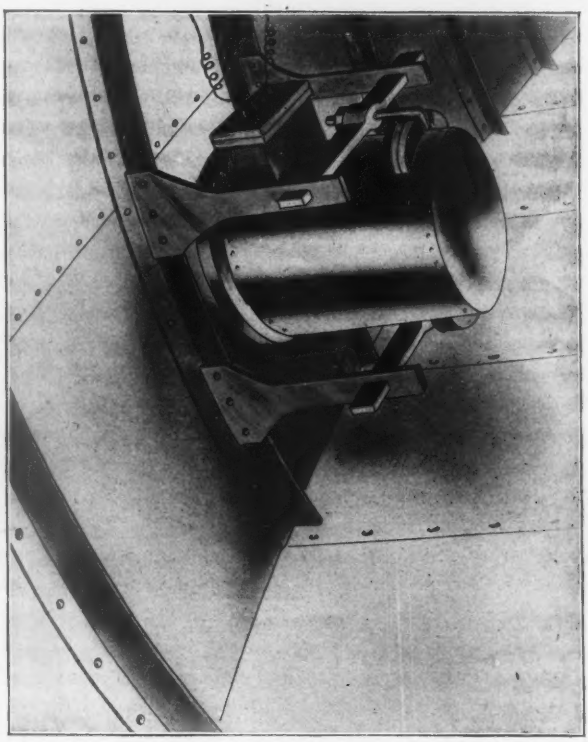


FIG. 3.—TRANSMITTER TANK

were coming, they were abandoned. It was soon found that the tank with an immersed microphone was the key to the whole situation, both for the reception of submarine sounds on board ship and the transmission of them from one ship to another through the water. The tanks are clamped up against the side of a ship, as shown in Figure 3, one on the starboard and one on the port side. Two specially constructed

microphones of the granular type are placed in each tank, with wires leading up to the pilot house.

The type of apparatus for switching into circuit the different transmitters is shown in Figure 4. It is of metal, about 8 inches in diameter, finished in black nickel, and furnishes a very handsome and durable instrument. This box is generally located in the pilot house, although in some instances we have placed them upon the bridge or

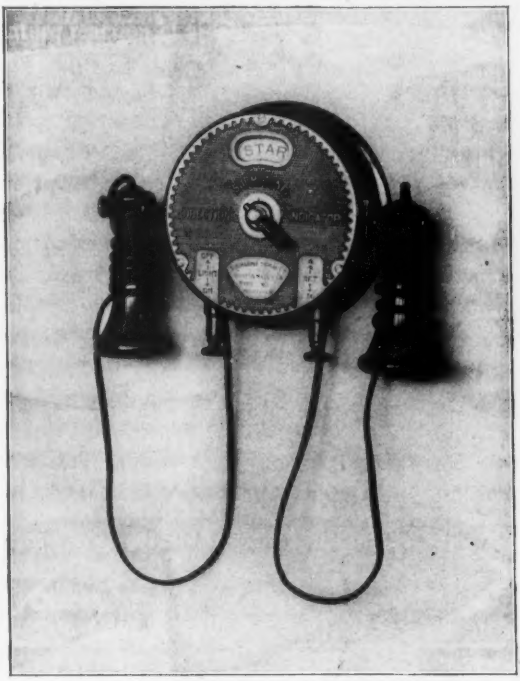


FIG. 4. — DIRECTION INDICATOR

in other parts of the ship. The method of operation is simple, and there seems to be no difficulty in explaining it so that it is plainly understood. We use two receivers, one at each ear, to cut out all outside sounds, so that the note of the bell can more clearly be heard. By a proper manipulation of the switches we may in turn listen in the port or starboard tanks and in either transmitter that we desire.

The method of ascertaining direction by means of submarine signals is very interesting.

Figure 5 shows the ship heading north when first observation is taken. The fainter sound heard on the port side of the ship proves

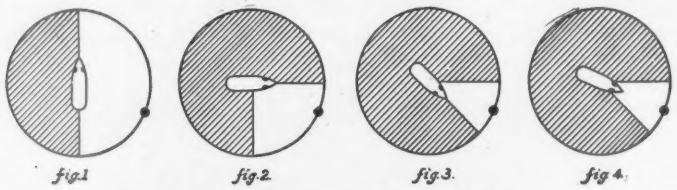


FIG. 5. — DIRECTION-FINDING DIAGRAM

that the bell must be somewhere on the starboard side, where the sound is relatively louder; therefore, half the circle is shaded to indicate that it does not contain the bell. The ship now turns to starboard 90°, heading east; and the fainter sound being still on the port side the shading is extended, leaving only one-quarter of the circle to explore. The ship turns 45°, heading southeast, and the fainter sound is now heard on the starboard side and the shading is again extended, thus showing that the bell is somewhere between east and southeast. Turning the ship back 22½°, the bell is heard equally well on both sides, thus indicating that it is dead ahead. As the ship sails toward the bell the sound steadily grows louder, thus confirming previous observations. With a little practice it is possible to ascertain the location of

FIG. 6. — CHURCH BELL SUBMARINE BELL

the bell within one-quarter of a point of the compass. This is being done constantly, and even more accurate locations have been found.

The range of the bell varies according to size, the energy put into the clapper striking the bell, and other conditions.

The weight which we have found to give the best success is about 160 pounds, Figure 6 showing the relative proportions of the bell and the peculiar construction of the sound bow. In bells rung in the air — church bells, etc. — the sound bow is thin, being, proportionally, not a great deal thicker than the sides of the bell as shown in the other section. This must of necessity produce a lower pitch than one where the sound bow is of greater thickness and of the same diameter. As a matter of fact, the pitch varies directly as the diameter and as the thickness of the sound bow.

It has been proven by experiment that the bell of higher pitch can be heard farther and more clearly than the one of lower pitch. The lower tones are absorbed by the viscosity of the water, and thus, as can easily be seen, the sound of higher pitch will extend to a greater distance.

The means employed for the ringing of bells are electricity, steam, compressed air, wave motion, and hand power.

The first bell of any size to be installed, and one of the most successful, weighed 1,000 pounds and was operated by electricity. This was moored at the bottom of the sea off Egg Rock, Lynn, for nearly a year, and could be heard up to a distance of twelve miles.

A type of striker used at the present time on lightships and operated by compressed air is shown in

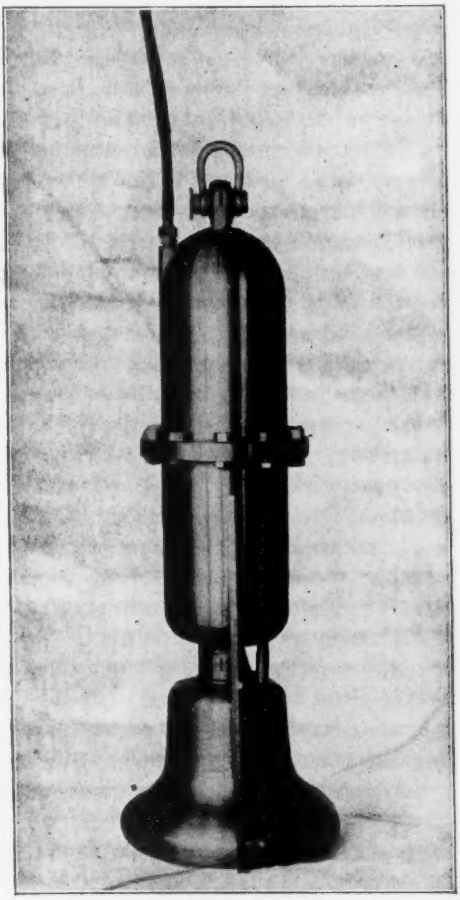


FIG. 7. — PNEUMATIC BELL RINGER

Figure 7. This has its mechanism enclosed in a case directly over the bell, which is suspended 25 feet under water. The method of operation is simple, and it has proved to be durable under all conditions. Air is supplied to the bell mechanism by means of a small compressor operated by steam in the engine room. The apparatus requires but little attention, and the intensity of sound produced by it seems to be greater than that hitherto used.

As all dangerous shoals and coasts are not indicated by lightships, it has been found necessary to submerge a bell by means of fastening it to a buoy suitably anchored, or of mounting the same on the bottom of the sea. The latter case I will take up first. The first experiment along this line was that of the 1,000-pound electric bell heretofore mentioned. Two years elapsed before anything else in this direction was done, and then it was decided to establish an experimental station at Point Allerton. Permission was obtained from the government, and the work progressed rapidly. It was decided to mount an electric bell in the main channel directly between Boston Light and Boston Lightship, about two miles and a quarter from Point Allerton. A small house at Allerton was obtained for a power station, equipped with the necessary apparatus, and an armored cable was laid from this station to the point in the harbor desired. A bell mount of the tripod type was built, and an enclosed type of bell placed there. The weight of the apparatus with the bell attached was about four tons. The cable was fastened to one of the legs of the tripod and connected by suitable junction boxes to the bell. Within the case of the bell was a powerful electromagnet directly connected to the clapper arm of the bell. By means of a controller in the station on shore any code could be rung.

The armored cable contains four wires; two convey the current to and from the magnet in the bell, and the other two are connected at the bell end to a telephone transmitter in the case of the bell, and at the shore end to an ordinary telephone receiver in the station.

The switchboard is fitted up for the attachment of duplicate sets of bells, engines, and controllers, so that if one set of apparatus gives out the other may be immediately switched in without loss of time, thus ensuring a constant signal. The enclosed bell remained in operation for a considerable length of time, and was then taken up to give way to an experiment on a different kind of bell. This was the ordinary open style, weighing about 160 pounds, and the same type of mechanism operated it as was used in that of the enclosed bell. This is at the

present time in operation at the mouth of Boston Harbor, and is anchored in about twelve fathoms of water, the bell itself being about nine fathoms below the surface.

To mark the position of the bell a light rope is run from the tripod to the surface of the sea, and there a small marking buoy is attached. Great difficulty is often experienced in attaching a buoy so that it will stay; there are the elements, the screws of passing steamers, or the knife of the fisherman to sever the cord by which it is fastened.

Still another form of bell-ringing mechanism is that known as the bell buoy. This consists in utilizing the motion of the waves for ringing a bell submerged below its surface. Owing to the tremendous waves along our coast, it is found necessary to build the apparatus of exceeding strength. Figure 8 shows a form of bell buoy which was placed in operation in Boston Harbor in 1903. It was located near Harding's Ledge, a short distance from the whistling buoy.

Several buoys of a modified form have already been placed off the Canadian coast, and owing to the importance of this type of apparatus continued experiments are being performed in Boston Harbor. The bell is heard at a distance of six miles.

The uses to which the submarine signal may be put are practically unlimited, and space prevents my giving more than a few of the most important ones. A practical trial is that of equipping fishing schooners with receiving apparatus and placing a small dory bell in each of the boats carried by the ship. Time and again men have gone out from a schooner fishing, fog has come up and the schooner has been unable to locate one or more of its boats; the consequence is, the men are tossed about and finally die of cold, or their boat is overturned by the waves. Now, when such a contingency arises, the men simply sit still in their boats, suspend the bell over the side, and begin ringing; the schooner equipped with ears hears the signal, and, being able to locate its direction, can pick up its boats with the greatest ease. This has been demonstrated repeatedly, and has proved of the greatest benefit to all concerned.

The tremendous difficulty of detecting sound signals in the air — to ascertain their direction, etc., in fogs — goes to show that the submarine signal will prove of the greatest importance. As has been seen, during a heavy storm or fog it is practically impossible for mariners to place any dependence upon the various fog signals. A great deal of time and money has been spent to invent apparatus for improving these

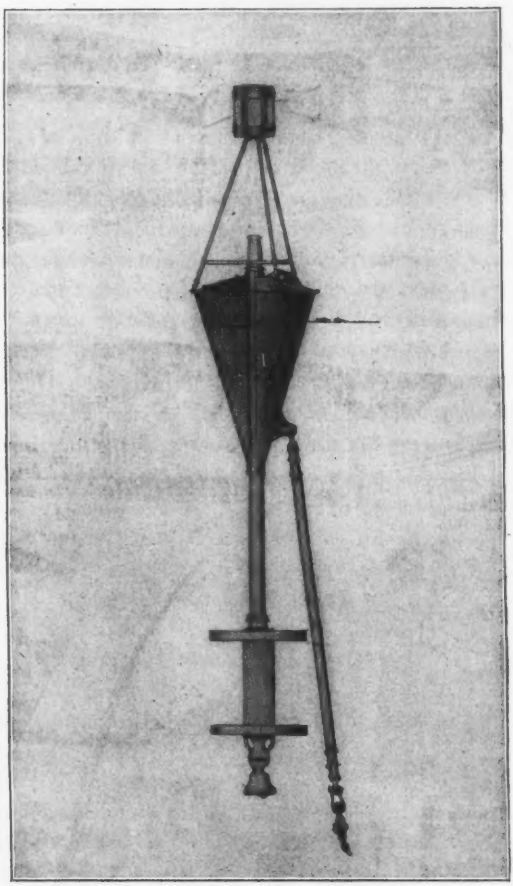


FIG. 8. — WAVE-OPERATED BELL BUOY

signals, but they have all proved more or less untrustworthy. The failure of the air to transmit sound equally under all conditions, in all directions, is a source of great danger to mariners, but now comes the submarine signal. This is not affected by wind, waves, fog, or any atmospheric conditions whatever, and absolute dependence can be placed upon the possibility of locating one's course.

A practical example of the above took place off Newport last August. Several of the battleships of our North Atlantic squadron

were cruising about outside the harbor. The *Maine* and *Alabama* had been equipped with submarine apparatus, while the *Iowa* was unequipped. The submarine bell on Brenton Reef Lightship was kept constantly ringing during the fog; and while the *Maine* and *Alabama* were able with the greatest ease to locate the lightship and their position by means of this device, the *Iowa* was unable to do so, and collided with the lightship. Rear Admiral Evans, who was on board the *Maine* at the time, says that the submarine signal was of the greatest assistance to him in locating his course into the harbor.

Up to the time of the invention of the submarine the battleship's foe had always been visible to the eye of the ship except in a very dense fog, but now comes the hidden enemy. Darkness had called for an eye in the battleship, and inventors responded with the search light; but the submarine asks for an ear, and now the ear has been provided.

Experiments conducted at Newport with a submarine torpedo boat have demonstrated the fact that its approach can be detected when the submarine is two miles away, the swish of the propeller and the thud of the engines having been distinctly heard and its location accurately ascertained.

Of paramount importance is the fact that the use of this invention will prevent collisions at sea, which have been so frequent and disastrous in the past. A bell is suspended in a large tank of liquid in the bow of each ship. This is rung by power, either hand or otherwise, and its sound, passing through the sides of the ship and through the water, is picked up by the ears of the approaching vessel. The latter, by varying her course ever so slightly so as to bring the sound a little louder in either the port or starboard receiver, will thus pass by on the corresponding side of the boat which she is approaching. This has been demonstrated very successfully by the Metropolitan line, plying between Boston and New York.

A wide field of possible usefulness is thus opened up, for by means of certain sound producers within the walls of ships below the water line, telegraphic communication at sea can take place between boats several miles apart.

Recently an equipped steamer located another by the sound of her screws when four and one-half knots distant. Is it not possible that Admiral Kamamura could have heard the Vladivostok fleet when he missed it in a fog by a distance thought to be less than three miles?

Did space permit, I should consider various other uses of the submarine signal, but I have given those which will appeal to all as being a great step in the right direction for the safeguarding of lives and shipping.

An interesting feature of the submarine signal is that sound will not travel from air into water or from water into air to any extent. The medium in which the sound is produced must be practically the same as that in which the wave is transmitted. If a bell is submerged in a tank full of air and no water allowed to enter, its strokes can be heard only in the immediate vicinity. A person standing on the deck of a ship from which a submarine bell is suspended can distinctly hear the strokes, but by moving away a distance of two or three hundred yards the sound will scarcely be audible.

The design of the different kinds of apparatus for mounting and operating bells brings up many problems, about which much of interest might be said. Suffice it to say that in dealing with the elements we are working against tremendous forces, and ones which cannot be overestimated in the design and calculation of machines to be so constructed as to resist their action for a considerable period of time.

With regard to the progress made in the adoption of the submarine signal the past year, a few words may not be out of place.

The Canadian government, after a long series of tests, placed orders for the establishment of numerous stations along the St. Lawrence and its eastern coast. A number of its boats have been and are being equipped with the receiving apparatus.

The German government has installed a number of bells off its coast, and the North German Lloyd and Hamburg-American lines are being equipped.

Trinity House, the English Lighthouse Board, has adopted the system after exhaustive tests, and at the present time all the transatlantic steamers of the Cunard line are being furnished with the apparatus.

The first bell in English waters was placed on a lightship off Liverpool, one of the pneumatic type being used. The *Lucania* tested it on September 23 last, and while going at nearly full speed had no difficulty in locating the position of the bell at a distance of nine and one-half knots. The official tests, which were concluded October 1, were entirely successful.

With permission of the United States government, the company

has installed at its own expense submarine bells on all the lightships from Yarmouth to Philadelphia. While this country has not yet adopted the system, it has taken and is taking a great interest in the invention, and for some time has been conducting an exhaustive series of tests under all conditions. Several of the battleships have been equipped, and the results obtained from them have been uniformly successful.

Numerous steamship lines running out of Boston and New York along our coast have had the apparatus installed, among them being the Metropolitan line, which has made constant use of the signals for over two years.

Other foreign countries than those mentioned are taking an active interest in the system; and I think that I do not over-prophesy when I state that the coming years will witness radical improvements in the different signaling systems throughout the world for the safeguarding of lives and property at sea.

CONTRIBUTION FROM THE CHEMICAL LABORATORIES OF THE MASSACHUSETTS INSTITUTE OF TECHNOLOGY

SOME EXPERIMENTS ON THE FUEL VALUE OF BITUMINOUS COAL ASHES[1]

BY HENRY FAY AND F. W. SNOW

DURING the winter of 1902–03, when the scarcity of coal was so great, it was considered desirable to know the exact amount of unburned coal which was being thrown away in our ordinary soft coal ashes. From some experiments carried out under the direction of and reported upon by the late Colonel Waring,[2] the amount of unburned coal seemed to him large enough to warrant the city in recovering this coal, and he also recommended various uses for the ashes. By means of a specially constructed small boiler, built on the order of a Rumford calorimeter, measurements were made of the unburned coal in the ash. The amount of waste coal in ashes examined varied from 20 per cent. to 40 per cent. by weight. If the ashes from the tenement house district be included the average would fall to about 20 per cent. It is further estimated that on this average there would be lost about 125,000 tons of coal for every 1,000,000 cubic yards of ashes. These numbers seemed to show such an appalling loss that it seemed highly desirable to subject the question to further experiment. As the method for determining these values was not strictly accurate it was decided to repeat some of this work in such a way that the personal element would be reduced to a minimum, and to express the results in terms of standard values.

In order to test the fuel value, ashes were obtained from four sources, viz., boiler room in the Rogers Building of the Massachusetts Institute of Technology, the Edison Electric Light Company, the Hotel Berkeley, and from a large packing house in which was used a mechanical stoker. These four samples will be referred to as A, B, C, and D, respectively.

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[1] Reprinted from the Journal of the American Chemical Society, May, 1905, XXVII, No. 5.

[2] Report of the Department of Street Cleaning of the city of New York, 1895–1897.

Starting with barrel lots each one was carefully weighed, and was then subjected to a screening process, in order to classify the material into coarse, medium, and fine ashes, so that in case there was enough coal in any one of these products to warrant its recovery a commercial extraction might be developed. These separate lots were weighed, and then sampled by coning and quartering. The final sample in each lot was then crushed and powdered, and from this material the calorific value was obtained. In this way the calorific value of samples from the coarse, medium, and fine ashes was obtained, and represented a true average of the whole.

All determinations were made in a Mahler bomb, with all the precautions necessary for accurate work, with the exception that no corrections were made for sulphur compounds, which may have been in the ash or in the coal which it was necessary in some cases to add. The values which are given, therefore, are not, strictly speaking, absolute values. The corrections which would be necessary, however, would be exceedingly small, and the values given are not far from the actual truth. As all experiments were carried out under the same conditions the values are strictly relative. Attempts were made at first to burn the ash direct, but this was successful with the richest products only. In the poorer products there was some combustion, but the heat developed was sufficient to soften the slag, which formed a glassy mass, protecting the unburned part from further action of the oxygen. On account of this difficulty it was found necessary in each case to add a weighed quantity of standard coal, and to burn this with the ash. A blank determination of the calorific value of the coal was made before each determination of the ash, and, knowing the number of calories contained in the coal, the difference represented the number of calories in the ash.

The following table shows the results obtained in the screen analysis and the value in calories of the various products. It will be noticed that the percentages given are obtained from comparison with a coal giving 8,500 calories, instead of the actual fuel value of the coal from which the ash was obtained. This was considered desirable, since it was necessary in some cases to add some such coal to the ash in order to make a perfect combustion.

Sample.	Screen analysis.	Weight in kilos.	Percentage weight.	Total calories.	Calories per gram.	Percentage of unburned coal compared with a coal giving 8,500 calories.
A	On 1-inch mesh	16.2	49.85	1320.3	81.5	0.96
	Through 1 on 2	9.4	28.92	2596.3	276.2	3.25
	Through 2	6.6	20.31	1840.1	278.8	3.28
	Loss	0.3	0.92	. .	. .	. .
B	On 2-inch mesh	20.5	44.4	45811.5	2234.7	26.29
	Through 2 on 4	14.1	30.5	24648.2	1748.1	20.51
	Through 4	11.5	24.9	10574.2	919.5	10.82
	Loss	0.1	0.2	. .	. .	. .
C	On 1-inch mesh	4.8	11.4	2674.1	557.1	6.55
	Through 1 on 2	8.1	18.9	4770.1	588.9	6.93
	Through 2 on 4	8.6	20.0	4767.8	554.4	6.52
	Through 4	20.8	48.6	. .	. .	. .
	Loss	0.5	1.1	. .	. .	. .
D	On 2-inch mesh	33.0	23.86	35805.0	1085.0	12.76
	On 4-inch mesh	39.7	28.71	83688.0	2108.0	24.80
	Through 4	65.4	47.28	101370.0	1550.0	18.24
	Loss	. .	0.15	. .	. .	. .

It will be seen from an inspection of the table that in two of the samples the value in coal approaches the results reported upon by Colonel Waring, and in those two it is not uniformly distributed in the different sizes. In sample B the highest values are obtained, with 26.29 per cent. in the coarse material, which was composed largely of black clinker, holding mechanically enclosed coke and coal. This appearance was also characteristic of the smaller sizes of this sample, indicating a fairly poor coal to start with and considerable neglect on the part of the fireman. While the amount of unburned coal actually present seems high, judging by the figures which were obtained, it does not seem to be in a form which would make it worth while to save. Instead of existing in the form of separate pieces of coal, most of it was in the form of coke, adhering firmly to and partially fused into the clinker. A more careful fireman certainly could have decreased this value very considerably. In sample D the material on the 2-inch mesh also shows a high value. This is, however, to be traced directly to the character of the slag which is formed on heating. The clinker melts at a low temperature, enclosing coal and coke, and falls through the grate in the form of round pellets of slag. In this material there is apparently no coal, and, judging alone from the appearance, it would be pronounced free from it, but on breaking open the shell of a pellet there is invariably

found some coal enclosed. This material would not appear to have much value, notwithstanding the high percentage of unburned coal found.

Sample A represents the average run of ash from a good grade of Pocahontas coal. It was taken from the middle of three grates. The ash from the top grate consists only of very coarse clinker, while that from the lower grate contains only very fine ash, both, judging from the appearance only, apparently free from coal.

The material used in this work represents only a very few of the large types of plants, and consequently it would be unwise to draw from the results any definite conclusions. It is believed, however, that the results represent something near the average. In the cheap tenement districts there would, undoubtedly, be found very little coal, because of the scrutiny with which the ash is sifted and picked over. On the other hand, from the private residence and apartment house district, where the waste is larger and where there is little or no attempt to work over the ashes, the average would probably be higher than the results reported here.

The average per cent. of unburned coal for each sample is, respectively, 2.49, 19.20, 6.66, and 18.60, and the average for the four only 11.98. This is very considerably lower than the average values reported upon by Colonel Waring, and it is believed that the expense of collecting and working the material of this kind would exceed the profit on the recovered product, unless the recovery was done in connection with some scheme for the utilization of the clinker and fine ash.

This conclusion, however, should be accepted only as tentative, as it would be necessary to use a much larger series of samples, not only of bituminous but also anthracite coals, for a final decision of the question.

BOSTON, February 23, 1905.

GENETIC AND STRUCTURAL RELATIONS OF THE IGNEOUS ROCKS OF THE LOWER NEPONSET VALLEY, MASSACHUSETTS[1]

By W. O. CROSBY

Introduction

The Lower Neponset Valley, or, more specifically, that part of the valley of the Neponset River within the limits of the Boston Basin, properly embraces all that part of the Boston Basin between the Blue Hills — a denuded anticlinal axis dividing the Boston Basin from the parallel and overlapping trough of Carboniferous sediments known as the Norfolk Basin — and the broad band of conglomerate extending westward from Savin Hill on Dorchester Bay, through Dorchester, Roxbury, West Roxbury, Brookline, and Newton, into Wellesley and Needham. This great belt of conglomerate, some three miles in normal breadth, is, structurally, one simple, flat-topped, and somewhat unsymmetrical anticline, the central and dominant arch of the Boston Basin (the Shawmut anticline), separated from the Blue Hills, or southern highlands, by the Lower Neponset Valley, and from the northern highlands by the Lower Charles Valley, each of these main lateral valleys exhibiting in the general view a synclinal structure, with slate as the prevailing surface formation, but being withal as complex in geological structure as the central ridge or water parting is simple. As thus defined, the Lower Neponset Valley is, west of Boston Harbor, a rectangular area some three miles wide and eight to ten miles long, including on the mainland small portions of the towns of Canton and Dedham, the whole of Hyde Park, the northern half of Milton and Quincy, and the southern

[1] Published previously in the American Geologist, **36**, pp. 34–47 and 69–83. This paper is an advance presentation in outline of a portion of Part IV of the author's detailed and systematic study of the geology of the Boston Basin, in course of publication in the series of Occasional Papers of the Boston Society of Natural History. For the petrographic distinctions in this field the author is indebted to Dr. Florence Bascom, whose preliminary observations on the volcanics only have been published (Bull. Geol. Soc. America, 11, pp. 115–126), and whose more complete and elaborate work on both the volcanics and plutonics awaits publication in connection with the forthcoming Part IV of the Boston Basin series.

half of West Roxbury and Dorchester. It is an area of great topographic as well as geologic complexity, and, although in general low-lying, includes in Bellevue Hill the highest land within the Boston Basin. The district here included in the Neponset Valley is not now wholly drained by the Neponset River, this study naturally following geologic more closely than topographic or hydrographic boundaries.

The Lower Neponset Valley is essentially an epitome of the entire basin, since it also consists of a central anticline of conglomerate bordered on either side by a well-defined slate syncline. The southern syncline, extending through Milton and Quincy, widens rapidly eastward, a somewhat open and composite trough, while the northern syncline, extending through West Roxbury and Dorchester, is a relatively deep and narrow isocline.

The immediate valley of the Neponset is developed in the complex and strongly denuded anticline which thus divides the more southerly of the two main troughs of the Boston Basin, and which narrows eastward for the simple reason that the axis pitches or inclines in that direction. The prevailing sedimentary rock of this belt is conglomerate, and the attitude or structure of the conglomerate as a whole is anticlinal. It dips northward along the northern border, passing beneath the slate of the deep and narrow Dorchester-West Roxbury syncline, while along the southern border the dip is southerly and the conglomerate passes below the slate of the much broader and composite Quincy-Milton syncline. That the anticline itself is not a simple arch is plainly indicated by the narrow band of slate developed at intervals along the middle of the conglomerate belt; and the existence of at least two anticlinal axes, pitching to the east and rising to the west, is further indicated by the fact that toward the west, where erosion has cut through the conglomerate and interbedded flows of basic lava, we have exposed, not one, but two, ridges of the underlying crystalline rocks, granite and felsite, representing the floor upon which the conglomerate series was deposited. These two axes are, at most points, of unequal prominence; and in their denuded western extensions the northern axis largely predominates, forming the broad, irregular, and broken ridge projecting into the Boston Basin from the western highlands of Dedham and Needham, and including the granite, quartz porphyry, and felsite of the Bellevue Hill district and the Stony Brook Reservation, the felsites of the northern part of Hyde Park, and the felsites and more basic lavas of the Mattapan district of Dorchester. The minor southern

axis is seen in the narrow band of felsite and basic lava lying mainly south of the Neponset, between Readville and Milton Lower Mills.

Over a part of this area several flows of basic lava or andesite are interstratified with the conglomerate, and during the geological revolution or period of disturbance following the accumulation of these strata and the formerly overlying slate upon the old floor of felsite and granite they were forced into a gigantic arch from one to nearly three miles broad. This great fold, however, was partially broken down in the making, and its collapse was attended by the formation of the minor folds and numerous faults. Subsequent erosion has been so extensive as to remove the entire thickness of slate from the crest of the great anticline, except where it has been carried down most deeply by these minor folds and the faults, occurring now in narrow and discontinuous belts wedged in between the larger masses of conglomerate. The erosion has also been sufficient to cut through the conglomerate series and the interbedded andesite toward the western end of the arch, where they were most elevated, and thus expose the ancient foundation of felsite and granite.

Probably no phase of this study possesses a greater intrinsic interest than the comparison of the denuded major axis of the Neponset anticline with the Blue Hills complex, which is but the denuded axis of the great anticline separating the Boston and Norfolk Basins; and aside from the disparity in area, it is surprising to find how marked is the similarity, except in minor details, and how few are the vital contrasts. In general terms it may be stated that hardly anything is precisely similar in the two areas, and nothing is radically different. In the smaller area as in the larger we have isolated masses of Cambrian strata involved in a complex of post-Cambrian granitic rocks, including the normal granite, the contact zone of fine granite and quartz porphyry, the effusive felsites, and the intersecting dikes of diabase of several different systems. The chief contrast is found in the relatively greater abundance in the Neponset complex of the effusive felsites, their more varied character, the great profusion of dikes of felsite in the granites, the more positive identification of some of the principal vents or points of emission of these acid lavas, and the far more complete and clearer exhibition of their relations to the later basic lavas and the enclosing Carboniferous strata.

Among the problems of special interest presented by the Neponset anticline, and apparently admitting of successful determination, may be

mentioned: the detailed relations of the rocks of the basal complex; the mutual relations of the acid and basic lavas — rhyolite (felsite) and andesite; and the relations of both types of volcanics to the sedimentary rocks.

The Basal Complex

The basal complex may best be defined as comprising all of the pre-Carboniferous terranes of this region, both sedimentary and eruptive; or, more specifically, as consisting of the Cambrian strata and any other pre-Carboniferous and pre-granitic sediments which future investigation may prove to exist here, together with the intersecting and associated igneous rocks of pre-Carboniferous age, including the normal granite or main body of the batholite, and its contact zones of diorite, fine granite, and quartz porphyry, and the dikes, necks, and flows of acid lavas or felsites. As thus defined, the igneous part of the complex is clearly the product of the chemical and textural differentiation of a single great body of magma, embracing, besides the truly plutonic mass or batholite proper developed, with its variable contact zone, under and in the Cambrian strata, the intrusive and effusive masses evolved, after extensive erosion of the Cambrian cover, from either still unsolidified or remelted deep-seated portions of the batholite.

That the batholite, with the complicating sedimentary and igneous phases which give it the character of a true and typical complex, is continuous under all the newer formations of the region, and in its successive phases essentially contemporaneous throughout, is highly probable; and the variations observed from point to point must, therefore, be regarded either as actual, and due in part to differences in the original magma resulting from the fusion of the pre-Cambrian floor and in large part, also, to the varying thickness and composition of the original Cambrian cover, or as merely apparent, and due to the varying depths of pre-Carboniferous and post-Carboniferous erosion; or, again, as due to the localization of the intrusive and effusive phenomena which followed the formation of the batholite proper, adding greatly to its structural complexity.

If, with these ideas in mind, we compare more particularly than heretofore the portion of the basal complex rising westward from beneath the Carboniferous sediments of the Neponset Valley with the portion exposed, as the result of still more extensive erosion, in the Blue Hills area, we find the more notable differences to be as follows:

First, the normal granite of the Neponset Valley is prevailingly coarser-grained and the ferromagnesian constituent (chiefly hornblende) is more generally and extensively altered (chloritized). Second, the differentiation of the contact zone appears to have been almost wholly textural, and not, to any important extent, chemical in the Neponset Valley district; and hence we find here only traces of diorite (which is also true of the Blue Hills) and nothing closely corresponding to the basic porphyry and the basic phase of the fine granite of the Blue Hills area. Third, the effusive acid lavas or felsites are, relatively, more abundant and far more varied in the Neponset Valley than in the Blue Hills. Fourth, the dikes of both acid and basic lavas so characteristic of the basal complex in the Neponset Valley are practically or wholly wanting in the Blue Hills. Fifth, the necks or actual vents of the effusive acid lavas are far more normally and typically developed in the Neponset Valley than in the Blue Hills, while the vents of the basic lavas are wholly wanting in the latter area. Sixth, the dikes of diabase, which are found in the eastern and northern parts and are practically wanting in the main range of the Blue Hills, are, in the Neponset Valley, characteristic of all parts of the complex as well as of the overlying sediments, no considerable area being free from them. Seventh, erosion has left in the Neponset Valley section of the complex, so far as it is now exposed, only very scanty traces of the original Cambrian cover.

General History of the Complex

After what precedes a brief statement will suffice here, the main purpose being a more systematic outline, prefatory to the lithologic and structural details of the complex. As in the Blue Hills area, this area or part of the general batholite of Eastern Massachusetts is believed to have been developed beneath a great thickness of Cambrian, and possibly of later, sediments, of which erosion has left only a few highly altered remnants. The thickness of the Cambrian cover was due primarily to extensive sedimentation, and secondarily and chiefly to severe or isoclinal plication. The thickening of the supercrust thus determined was sufficient to induce a rise of the isogeotherms, an outflow of the subterranean heat, so marked as to involve softening and final fusion of the subcrust or floor on which the Cambrian sediments were deposited, developing thus a great body of granitic magma, the corrosive action of which led to the absorption of considerable volumes of the

sedimentary cover and gave rise, no doubt, to the normally highly irregular and unconformable contact.

This thickening of the supercrust and consequent great heat invasion was, doubtless, accompanied by a strong elevation of the surface, permitting extensive erosion, which, in turn, favored the refrigeration of the batholite and the development from the originally homogeneous magma of a vast body of normal granite, with a contact zone consisting normally of an inner layer of fine granite and an outer layer of quartz porphyry, both phases of the contact zone being the products mainly of a textural rather than a chemical differentiation of the magma.

Long-continued erosion, removing in large part the sedimentary cover of the batholite and probably cutting at some points through its contact zone into the normal granite, was followed by a period of volcanic activity, due, possibly, to cracking and hydration of the body of the batholite, during which acid lava, chiefly rhyolite, now existing in a devitrified form as aporhyolite or felsite, was poured out over the eroded surface of the batholite. Several of the volcanic necks or vents of these effusive eruptions have been definitely located and their details of form and structure more or less fully worked out. From the vents or chimneys of these most ancient volcanoes of the Boston Basin, radial dikes of felsite extend outward into the granitic rocks. As a chronologically distinct record the complex was now complete, but it was destined to be still further complicated, for these effusive acid eruptions appear to have marked the beginning of the progressive subsidence which inaugurated the deposition of the Carboniferous sediments, beginning with the great conglomerate series; and during the subsidence and clastic sedimentation the effusive eruptions continued, but became of more basic character, grading from rhyolite through trachyte to andesite, which in its present altered form as apoandesite or porphyrite has been heretofore classed as melaphyre, but is now known to be less basic than that type. The andesitic eruptions from, presumably, greater depths than the source of the acid lavas are marked by fissure-like necks, by numerous dikes cutting all the older rocks, and especially by successive massive flows or contemporaneous beds intercalated in the conglomerate series.

The volcanic activity finally ceased, and continued subsidence introduced the deep water conditions, permitting the deposition of the slate series into which the conglomerate series gradually merges upward. The deposition of the slate series was closed, it is supposed, by the

Appalachian revolution, during which the Carboniferous sediments were strongly folded and faulted and injected by still more basic magma from, possibly, still greater depths, forming the older or east-west series of diabase dikes, now largely chloritized to typical greenstone. Still later, and probably contemporaneously with the Triassic sedimentation and accompanying igneous activity in the Connecticut Valley, were formed the diabase dikes of the newer or north-south series.

With this the rock formations of the Neponset Valley were complete, and its later geological history is recorded only in the erosion accomplished during later Mesozoic and Tertiary ages and culminating in the great ice invasion of post-Tertiary or Pleistocene time.

The Cambrian Strata

The existing small remnants, the larger less than 1,000 feet long, of the body of Cambrian strata which we suppose to have once formed a continuous cover over the batholite in the Neponset Valley, as in other parts of the Boston Basin, appear to be confined to the vicinity of the Boston and Hyde Park boundary, in the eastern part of the Stony Brook Reservation and the immediately contiguous territory.

The sedimentary rock of supposed Cambrian age is all slate of a uniformly massive, hard, and distinctly metamorphic character. The prevailing color is dark gray, but it varies to lighter shades, and very generally the rock is perceptibly veined or clouded with the green of epidote, indicating that the slate was originally more or less calcareous, the lime having as an essential phase of the igneous metamorphism combined with the alumina and silica of the slate to form epidote. This feature allies it with the lower Cambrian slates of Weymouth, Quincy, Nahant, etc.; but in other respects it bears a striking resemblance to the massive, gray, non-calcareous middle Cambrian slates, as these are developed on Hayward Creek in Braintree and along the north side of the Blue Hills. It exhibits in a good degree the characters of a true hornstone; but it is nowhere of flinty hardness, and the fact that it is never visibly micaceous testifies to the essentially non-alkaline character of the sediment. As a rule, the stratification is hopelessly obscure; but at a few points, which are so distributed as to cover practically the entire group of ledges, it is fairly distinct and entirely unequivocal. The attitude of the bedding is, as usual in the Cambrian of the Boston Basin, very constant, with east-west strike and vertical dip.

The essential relation of these sediments to the complex is clearly indicated, not alone by their metamorphic character, but also by typical igneous contacts with the fine granite and quartz porphyry of the contact zone, and irregular dikes or apophyses of the quartz porphyry and more regular dikes of normal felsite.

Body of the Batholite

Normal Granite. — This is a coarsely crystalline aggregate of feldspar and quartz chiefly, with a small proportion of a dark constituent regarded by Dr. Bascom as chloritized amphibole. The feldspars, according to this authority, include orthoclase, commonly of a pinkish tint due to oxidation, and a lime-bearing albite, in which the greenish tint due to epidotization is more or less marked. The analysis shows an acid rock similar to the normal granite of the Blue Hills, but rather more basic and richer in plagioclase, though poorer in the ferromagnesian constituent.

The outcrops of normal granite are chiefly confined to two rather irregular areas, and the general relations of these to the complex is not central, as might seem most natural, but peripheral. They form, respectively, the northern and southwestern borders of the complex, and converge, but apparently do not meet, to the northwestward, in the vicinity of Grove and Centre Streets. The disposition of the normal granite is such as to suggest at once a general monoclinal or shallow synclinal structure for the complex, the surface of the normal granite forming a trough the axis of which pitches to the southeast, thus allowing the normal granite to slope southward and northeastward beneath the contact zone of fine granite and quartz porphyry and a great thickness of volcanic and sedimentary formations. In the direction of its disappearance the normal granite does not reappear north of the Blue Hills; and undoubtedly its disposition, especially in relation to the unaltered sedimentary formations which meet it abruptly on the north in the West Roxbury district, finds its readiest explanation in a profound displacement along the northern border of the complex, with the downthrow, of course, to the north.

The normal granite is observed at many points to grade upward into the fine granite by which it is bordered, and its surface continuity is frequently interrupted by island-like outliers of the fine granite. These relations are particularly well exhibited in the broad and massive ledges

in the area bounded by Washington, Grove, and Centre Streets and Cottage Avenue, and nowhere more favorably than in the vicinity of the large quarry on Cottage Avenue, northwest of Washington Street.

Contact Zone of the Batholite

Fine Granite. — The chief difference between this type and the normal granite is textural. The essential minerals, according to Dr. Bascom, are the same, with the addition of a little microcline and oligoclase to the feldspars. Quartz is reported as more abundant and the chloritized ferromagnesian constituent as less so, and these distinctions are confirmed by the analysis, which shows higher silica and lower lime, magnesia, and iron.

The fine granite belongs to the contact zone, and hence overlies the normal granite. It might, therefore, where not removed by erosion, be expected to exhibit a broad areal development but for the fact that it is, in turn, covered by the quartz porphyry phase of the contact zone. In harmony with this general relation and the shallow synclinal structure of this part of the batholite, the principal area of the fine granite takes the form of an irregular V-shaped belt, 1,000 to 3,000 feet wide, separating the normal granite on the north and southwest from the quartz porphyry on the south and northeast, respectively.

As to the thickness of the fine granite we have no very definite clue. No approximately vertical or continuous section shows both the normal granite below the fine granite and the quartz porphyry above it. In other words, we have no data for a direct determination of the thickness save that it must exceed the height of the highest hill composed wholly of the fine granite, or say 75 feet. It would be readily deducible from the surface breadth if the dip were known. Assuming the dip to be low and inversely proportional to the surface breadth gives a maximum thickness of a few hundred feet at the most, and 100 to 200 feet may, perhaps, be accepted as a conservative estimate, confirming the conclusion reached in the study of the Blue Hills complex.

The fine granite of the contact zone is, in a fair sense, a bed of passage, since it grades downward into the normal granite and upward into the quartz porphyry; and normally its original contacts are nowhere sharply defined, but distinctly blending. It may be noted, however, that, as in the Blue Hills complex, the contact with the normal granite

though blending is rather abrupt, the complete transition from the one rock to the other being accomplished in some exposures in the breadth of a few feet, or possibly, in extreme cases, a single foot. Although the passage upward into the quartz porphyry is usually more gradual, all observers must recognize that the fine granite, so far from being all gradation, is chiefly remarkable for the uniformity of texture throughout almost its entire thickness. In fact, it rivals the normal granite in this respect. Locally, and especially near the quartz porphyry, it may pass into a true microgranite; but it is, in general, a macrogranite of very homogeneous aspect.[1] That the fine granite is older than the normal granite and younger than the quartz porphyry, and that these three distinct but blending sedentary zones of the batholite exhibit the structural relations which this sequence requires, will probably not be questioned by those familiar with the field evidence.

Quartz Porphyry. — This upper or peripheral member of the contact zone has been designated by Dr. Bascom the rhyolitic facies of the granite, or more succinctly rhyolite and more explicitly porphyritic aporhyolite; and for this usage the petrographic characters undoubtedly afford ample warrant. But in order the more sharply to distinguish this essentially plutonic type from the much younger and very dissimilar intrusive and effusive rhyolites, it is proposed to employ here the good descriptive term quartz porphyry. The rock in question is in every instance a true quartz porphyry, with conspicuous phenocrysts of both quartz and feldspar; and, as befits its plutonic origin, it is of remarkably uniform character, matching the granites in this respect; while the clastic, fluidal, and spherulitic structures so characteristic of the newer rhyolites are conspicuous by their absence. Such variation as the quartz porphyry shows is due chiefly to its gradation downward into the fine granite. As Dr. Bascom has noted, its texture, though aphanitic, allies it with the microgranitic phase of the fine granite, and, unlike the younger rhyolites, it is rarely truly cryptocrystalline.

In its distribution the quartz porphyry tends to form a V-shaped zone concentric with the fine granite and separating the underlying fine granite from the overlying effusive rhyolite or felsite. The lower border of the quartz porphyry is rendered rather vague and indefinite at most points by its blending contact with the fine granite. The upper border,

[1] The explanations of the homogeneity of the fine granite and its abrupt yet blending passage into the normal granite suggested in Part III of the Boston Basin Geology (Occasional Papers, Boston Society Natural History, 4, pp. 354 *et seq.*) are still regarded as valid and as applicable in this new field.

on the other hand, where the quartz porphyry meets the effusive rhyolites or felsites, is, in the nature of the case, sufficiently definite, but highly irregular, since we have here a true erosion unconformity; and the two formations, although of closely similar composition and probably derived from the same original magma, are strongly contrasted in structure and widely separated in geological time.

Summary and Comparison. — Neglecting unimportant occurrences of diorite and aplite, which may be described, respectively, as relatively basic and relatively acid phases or segregations of the normal granite, and hence as products of a chemical differentiation of the main body or primal magma of the batholite, we have now considered all of the sedentary or truly plutonic rocks of the batholite. These have been described in the order of superposition, which is, of course, the inverse order of age, since the refrigeration of the batholite must have progressed from the periphery downward or centripetally. That the differentiation of the normal granite and the contact zone, and the further differentiation of the fine granite and quartz porphyry of the contact zone, are not wholly textural is, as noted by Dr. Bascom, clearly shown by analyses, according to which the normal granite is the most basic and the fine granite the most acid, while the quartz porphyry is intermediate in composition, although not so in position. By way of explanation of this chemical relation, Dr. Bascom has suggested that specific gravity and convective currents may have been factors in producing a somewhat more acid peripheral zone to the batholite, while the outer or quartz porphyry border to this zone, following the general law of the order of crystallization (virtually fractional crystallization), by its earlier crystallization left the inner portion of the zone or fine granite more acid than either the quartz porphyry or normal granite. To this explanation may, perhaps, be added the influence of hydration. It appears reasonable to suppose that the primal magma of the batholite, formed under a thick and necessarily a hydrated sedimentary cover, and due in part to the absorption of large volumes of this cover, would naturally be more highly hydrated in its superficial than in its deep-seated portions; and since the characteristic elements of an acid magma, including silica and the alkalies, have a stronger affinity for water than have the lime, magnesia, and iron oxide characteristic of basic magmas, we have here a cause tending to keep, if not to make, the batholite superficially acid.

That, in comparison with the granitic rocks of other districts, this

part of the batholite was formed under a moderate depth of cover is believed to be indicated by the relatively slight amount of chemical differentiation, by the absence of an original micaceous constituent, and especially by the almost entire absence of a pegmatitic phase in the normal granite. The absence of marked differentiation extends, in the main, to the earlier intrusions in the batholite, since, with one exception, these are relatively acid, and differ but little in composition from the sedentary members of the batholite.

Pre-Carboniferous Intrusives

The earlier or pre-Carboniferous intrusive rocks of the batholite include the following types: granite porphyry, quartz porphyry, felsite, and acid andesite. The first three are acid and agree closely in composition, as stated above, with the sedentary types of the batholite, so that they may fairly be regarded as later extravasations from the deeper parts of the same great body of magma. The fourth type, on the other hand, is of distinctly subacid or neutral composition, as a partial analysis accompanying Dr. Bascom's description clearly shows. Furthermore, the dikes of this relatively basic type are, according to the rather meager but quite satisfactory evidence, older than all of the acid intrusives, suggesting eruption from a source below the normal granite, and hence during a time (possibly of marked elevation and erosion) when the batholite proper was congealed throughout its entire thickness.

The acid intrusions, on the contrary, including both dikes and necks, may, in the main, at least, as previously indicated, be correlated with the subsidence ushering in the sedimentation of Carboniferous times and accompanied by a rise of the isogeotherms sufficiently marked to reliquefy a portion of the ancient acid magma. This correlation is confirmed by the close agreement in composition of the acid intrusions and the normal granite, for the unquestionable connection of the acid intrusives (both dikes and necks) with the acid effusives or lavas, which rest unconformably upon the deeply denuded surface of the batholite, shows that in origin the intrusions are separated from the sedentary zones of the batholite by a vast time interval, during which the magma must have been mainly solid to have escaped marked chemical differentiation.

Acid Andesite Dikes. — This is a rock of distinctly neutral composition, analyses showing from 60 to 62.8 per cent. of silica, and Dr. Bascom's observations indicate a hornblende-bearing biotite andesite.

A single dike only has been studied in detail, but it is known to represent a more or less extensive series, the acid andesite not having been distinguished heretofore from basic andesite and greenstone diabase. This dike begins in the fine granite on Heron Street, near Washington Street, and, with a normal breadth of 20 to 25 feet, has been traced northwesterly, parallel with Cottage Avenue, into the normal granite and for a total distance of nearly half a mile. It is clearly cut by typical dikes of quartz porphyry and felsite, and the acid andesite occurs as angular inclusions in a great dike of granite porphyry. These relations give it at once a unique position among the basic intrusives of this area, and, so far as known, of the Boston Basin, by definitely fixing it, chronologically, between the batholite and all of the acid intrusives. Comparison is suggested at once with the more basic, pre-granitic dikes (diabase) in the Cambrian slates of the Blue Hills.[1] The latter are the only basic dikes in the Boston Basin known to be older than the granitic series of the complex, and the West Roxbury dike just described is the first relatively basic dike in the Boston Basin known to be intermediate in age between the sedentary zones and the acid intrusions of the complex.

Granite Porphyry and Quartz Porphyry Dikes. — In this instance, also, the detailed study has been limited to what is virtually one large and complex example; but the general conclusions thus reached are definitely known to be applicable to an extensive series of dikes. The fine granite of Bearberry Hill, in the northeast part of the Stony Brook Reservation, is traversed in a general northwest-southeast direction by a vertical dike of quartz porphyry 100 feet wide. The greenish gray, aphanitic groundmass of the porphyry is crowded with conspicuous phenocrysts of feldspar up to one-half, and even three-fourths, of an inch in length, while the more scattering, rounded blebs of quartz are commonly one-fourth to one-half inch in diameter. Altogether it is a striking rock, and one readily recognized and traced. The quartz porphyry is densely felsitic near the contacts, which are firmly welded, irregular in detail, and further characterized by occasional inclusions of the fine granite in the quartz porphyry and minor apophyses of the latter in the former. On this hill, also, the quartz porphyry dike is cut by a four-foot dike of compact and purple felsite, and gives off an oblique branch 20 feet wide, traceable for 1,000 feet, and cut by another felsite dike 10 to 15 feet wide.

[1] Occasional Papers, Boston Society Natural History, 4, p. 388.

The phenocrysts of the branch dike are relatively small and inconspicuous, and comparable in size with those of the contact zone, while this contrast between the main dike and its branch proves that in neither case can the phenocrysts be regarded as antedating the intrusion of the magma. On the other hand, the lithologic resemblance of the branch dike to the quartz porphyry phase of the contact zone must be regarded as a mere coincidence, since we have to do in the one case with the earlier phase of the batholite, and in the other with relatively late intrusions, cutting, as we shall see, all of the sedentary zones of the batholite from the normal granite to the quartz porphyry.

Southeastward the main dike is traceable across the reservation boundary and nearly to the Boston-Hyde Park line, where it is seen to cut the quartz porphyry of the contact zone and the enclosed masses of Cambrian slate. In the opposite direction from Bearberry Hill, across the drift-floored valley of Turtle Pond and beyond Washington Street, in the large Cottage Avenue quarry in normal granite, capped by fine granite, and exactly where the great dike of quartz porphyry might be expected to reappear, we find instead, and with the same trend, a dike of profusely porphyritic granite porphyry 30 to 50 feet wide. With aphanitic and firmly welded margins, it cuts, clearly and unmistakably, both the normal and the fine granite, and it is in turn cut squarely across by a small dike (2 to 4 feet) of felsite, in which the fluxion structure parallel with the irregular walls is beautifully developed. Apparently there is no reason to doubt that this intrusive granite porphyry, which Dr. Bascom regards as essentially identical in composition with the normal granite, is also simply a more crystalline phase of the intrusive quartz porphyry, the two rocks being part of one and the same continuous dike; and facts yet to be noted abundantly confirm this conclusion.

The next outcrop of this dike, where it crosses Heron Street, is also granite porphyry, but beyond this the quartz porphyry phase recurs, and the dike, now 75 feet wide, is lithologically indistinguishable from the Bearberry Hill section. From this point on it is near to and approximately parallel with the dike of acid andesite previously described, and the latter is cut by minor dikes or apophyses of quartz porphyry. The outcrops of both dikes are now interrupted by a swamp, beyond which the dike of acid andesite continues unchanged, while the porphyry dike, now 80 feet wide, is once more a typical granite porphyry, apparently repeated by an oblique strike fault and, as previously noted,

enclosing angular fragments of the acid andesite. Thus twice in a total distance of a little more than a mile the quartz porphyry gives way to granite porphyry. In neither case, unfortunately, can the transition be fully traced, and yet we may not reasonably doubt its reality. This remarkable and rhythmic textural variation in the contents of one and the same continuous fissure may, perhaps, be regarded tentatively as finding its most natural explanation in varying original depths of solidification. That is, if we may assume a natural gradation upward in the dike from granite porphyry to quartz porphyry, then a moderate amount of subsequent displacement, or even of unequal erosion, might suffice to give the alternations of texture which the outcrops now show. In this connection it may be noted that in the lowest outcrop of the main dike, at the western base of Bearberry Hill, the quartz porphyry is well advanced in the change to granite porphyry. It is a fair corollary of this explanation that the granite porphyry should be found chiefly in the normal granite, and the quartz porphyry in the fine granite. This relation is clearly realized in part, and would, perhaps, be more fully realized but for the fact that, as we suppose, the batholite suffered strong and unequal erosion before its injection by these acid intrusives.

Felsite Necks. — Besides its abundant occurrence in effusive forms or surface flows the devitrified rhyolite (aporhyolite), or felsite, has an important development in necks and dikes, which are undoubtedly contemporaneous with the acid effusives; and nowhere, apparently, in the Boston Basin are normal effusives more clearly or typically developed. Some of the felsite dikes are large enough to be regarded as the vents of effusive masses, and very probably several of them are deeply denuded necks. The more typical and unequivocal necks, however, are less dike-like in outline and far more diversified in structure, consisting chiefly of clastic lavas — agglomerate and tuff — suggestive of explosive eruptions toward the end of the volcanic activity and following more quiet liquid effusions. Three essentially distinct vents have been more or less fully worked out, and it is considered not improbable that others await recognition in the felsite areas. This appears the more likely in view of the fact that acid lavas of fluidal and autoclastic types, that is, lavas which were stiff enough at the time of their effusion to develop fluxion lines, or even to become brecciated by their own flow, would not spread far from the vents through which they reached the surface. We must recognize, also, the extreme probability that some vents are still concealed by their own sluggish effusions or by later sediments.

The three vents referred to as more or less fully identified are near the heart of the complex, and bordered either wholly or in part by the sedentary zones of the batholite, including the normal granite, fine granite, and quartz porphyry; and evidence is not wanting that they are in each case located on important displacements, one indication of this relation being elongation in a definite direction, the outlines being distinctly lenticular.

The West Roxbury Neck. — This neck is the most clearly exposed in outline and in structural detail, and probably the largest, as it is certainly the most indubitable of the series. It occupies approximately the irregular triangular area bounded by Grove, Centre, Stimson, and Washington Streets in West Roxbury near the Dedham line.

It is elongated in a general northwest-southeast direction, the extreme dimensions being approximately 1,200 by 3,500 feet. The major axis coincides in position and trend with the common boundary of the fine granite and the western area of normal granite, the evidence being quite conclusive that this line marks an important displacement. The sharp definition of this neck, with its continuous rim of granite, is, of course, chiefly due to the fact that erosion has removed the last vestige of the effusive felsite which we must assume to have once covered its site and a wide area of the enclosing granites.

Not to classify this sharply defined body of acid lavas as a true neck or vent would seem to necessitate regarding it as a depressed fault block or graben, a remnant of a once widely extended volcanic sheet covering the granites which has escaped erosion through the accident of displacement. But the varied and prevailingly clastic character of the lavas and the general structure of the mass are, at least, highly suggestive of a vent, and force the conclusion that there must be a vent somewhere in this part of the complex. Although, omitting intersecting dikes of felsite, andesite, and diabase, the neck is almost wholly composed of effusive types of felsite, it is yet, quite independently of the dikes, highly diversified in composition and structure — a constantly varying complex or chaos of fragmental, fluidal, and compact or structureless lavas. The clastic phase, ranging from the finest tuff to the coarsest breccia or agglomerate, largely predominates and gives character to the whole, leaving little room to doubt that the later eruptions, at least, from this vent were in part explosive. Although varying greatly in azimuth and inclination and usually much contorted, the normal attitude of the flow structure of the felsite is parallel with the axial plane

of the neck, or in the peripheral portions with the proximate wall of granite. The interest of the peripheral phenomena culminates in the southeastern extremity of the neck, where it is continued in the shattered zone of granite in which it had its origin as a complex of granite and felsite, the granite being cut in all directions by irregular branching and coalescing dikes of the felsite, which is brecciated, banded, compact, or porphyritic by turns, and encloses many large and small angular fragments of the granite.

While we need not doubt that the fragmental lavas are, in the main, true pyroclastics — the product of explosive eruptions — it is very probable that they are in part autoclastics, or breccias resulting from the continued movement of the magma after it began to stiffen and solidify. The distinction of these two types in the field must usually be a puzzling matter, so much depending on the nature of the matrix or groundmass; but it is assumed here that local homogeneity of composition (not of texture) and absence of granitic *débris* are characters belonging more normally to the autoclastics. In considering the distinction and probable relative abundance of the pyroclastic and autoclastic lavas, both of which are undoubtedly prominent features of this neck, and may also be designated, respectively, agglomerate and breccia, we may properly take account of the possibility that the eruptions were subaqueous, at least in part, and note the cracking and shattering of the lava that would follow its sudden quenching. It is doubtful, however, if much of the breccia has the crackled character, with accurately fitting fragments, which this explanation would require. Nevertheless the presence of water is plainly suggested by the rather distinct stratification of some of the finer tuffs, such as may be observed in the central part of the neck especially.

Attention is thus directed to one of the most interesting and puzzling features of the neck. This is a very compact gray, slaty-looking rock, irregular masses of which are enclosed in the more normal or unquestionable agglomerate, and also in the fluidal felsites, and occur only in the western central portion of the neck, all the outcrops being included within an area about 1,000 feet long in a north-south direction and perhaps half as wide. This material, which may be as distinctly, evenly, and finely, or as obscurely, stratified as any slate, was at first mistaken for an older slate enclosed in the volcanics. But further study of the field relations showed that it must be contemporaneous and essentially a tuff or consolidated ash. As noted by Dr. Bascom,

this conclusion is confirmed by both the microscopic and the chemical analyses. The combined alkalies are far higher than for a normal slate, and agree closely with those of the felsites. These masses range in extent from a few inches to many feet. They are sometimes ill-defined, cloudlike patches in the lavas; but more commonly they are sharply outlined, and the contacts with the felsite are unquestionably igneous, being firmly welded and the sediment well baked for a breadth of one to several inches. Even closely adjacent masses do not usually agree in dip and strike; but the relations are what might be expected in the case of a bed or beds of imperfectly consolidated ash disturbed by later eruptions, largely of an explosive character. The close relation of the consolidated ash or slaty tuff to the felsite agglomerate is clearly indicated in some instances by the intercalation of visibly clastic layers. Finally, we may regard the ash as the finest product of an explosive eruption which was in some sense subaqueous, closely followed by eruptions which were only in part of an explosive character, yielding, besides the true agglomerates, compact, fluidal, and autoclastic felsites intersecting and enclosing alike the agglomerate and the ash.

Accepting the West Roxbury neck as a true volcanic vent, as apparently we must, it may be assumed to have originated in a more or less complex and branching fault fissure, and the local widening of such a fissured zone to the present breadth of the neck when it finally became the locus of vulcanism would be a natural consequence of the explosive action of which we have such ample evidence. In other words, we need not assume that the granite was melted away, or forced out *en masse*, Pelée fashion; but it is sufficient to assume a splintering and shattering of the granite walls under the influence of shock and heat. The resulting granite *débris* would be borne upward by the constantly increasing volume of viscous lava made possible by the widening of the vent, and finally discharged, largely through the agency of violent explosions. This explanation, the essence of which is a gradual crumbling and exfoliation accompanied by cracking and rending of the granite walls of the primordial fault fissure, accounts for the general diffusion of granitic detritus through the clastic lavas, as well as for larger isolated masses of granite which now add to the diversity of the neck.

The Hyde Park Neck. — This large and composite neck occupies a more central position than the West Roxbury neck in relation to the complex, and presents some other distinguishing features. It is probably best regarded in detail as two necks developed on fissures, approx-

imately parallel with the major axis of the West Roxbury neck, but converging irregularly northwestward near the Cambrian outliers, and the united axes might be regarded as continued in the great dike of quartz and granite porphyry. Where most widely separated and most distinctly developed as necks, these fissures are clearly compensating displacements bounding a depressed area approximately half a mile wide.

The southwestern fissure, designated the Bold Knob neck, shows a wall of the massive quartz porphyry of the contact zone bordered on the northeast by several hundred feet in breadth of coarse felsite agglomerate, the felsitic matrix of which is packed with large, angular fragments of both felsite and quartz porphyry. Northeastward, or away from the wall of quartz porphyry, the agglomerate becomes rapidly finer, and shades off into fluidal, spherulitic, and other obviously effusive forms of felsite. Similarly the northeastern fissure, known as the Grew's Woods neck, shows an immense mass of exceptionally coarse agglomerate sharply limited on the northeast by normal granite. The agglomerate has a maximum breadth of nearly 1,000 feet, passing gradually, as before, into the effusive felsites, which are continuous over the area intervening between the two bodies of agglomerate. Not only has the effusive felsite, discharged by flow and explosion from these fissures, overspread the depressed area which they bound, but from this expanding area, as from a cornucopia, the felsite flows have spread eastward over a large part of Hyde Park and into Dorchester and Milton. Unlike the West Roxbury neck, and on account of the general eastward inclination of the geological structure of the district, erosion has not cut deeply enough to remove entirely the effusions of this most eastern of the recognized felsite necks.

Felsite Stocks. — Besides the large and essentially indubitable necks of acid lavas described in the preceding pages, we must, as previously noted, recognize several more or less probable stocks or plugs of felsite in the sedentary zones of the batholite. These masses, which may, perhaps, best be regarded as more deeply denuded as well as smaller necks, are intermediate, in size at least, between the undoubted necks and the normal felsite dikes. They are related to the necks in form and to the dikes in lithologic character, lacking entirely the clastic and fluxion characters and the general structural heterogeneity of the necks. One difficulty in regarding them as dikes is that they do not appear to occupy dynamic fissures, being chimney-like rather than dike-like in

form. The clearest examples are roughly circular or elliptical plugs 200 to 300 feet in diameter, isolated in and enclosing numerous fragments of the normal granite. The rock, although felsitic in general aspect, is perhaps better described as a dense, non-porphyritic microgranite. It is essentially homogeneous and structureless, except for an indistinct peripheral zone of true felsite, in part fluidal.

Felsite Dikes. — In the general view the entire area of the complex appears to be traversed by dikes of felsite. They are, however, especially characteristic of the sedentary zones of the batholite and the felsite necks, and are observed less commonly in the effusive felsites. In spite of the fact that they sometimes cut both the felsite necks and flows, the dikes as a whole are undoubtedly best regarded as essentially contemporaneous with the acid volcanics, and we may fairly suppose that in some instances they have formed effective vents. We have seen that they intersect the great dikes of quartz porphyry and granite porphyry; but here again an important difference of age is not, apparently, a necessary inference. The relation of the felsite dikes to the necks is in some cases distinctly radial, but a broader view shows that with few exceptions they tend to be normal to the major axes of the felsite necks and the fracture zones in which the necks have been developed. The prevailing trend, therefore, is northeasterly and southwesterly.

In the extension of the axial shear zone of the West Roxbury neck the felsite forms a plexus of irregular intrusions, which branch and coalesce in a quite remarkable way; while the true dikes represent the filling of comparatively simple and sharply defined transverse fissures, due, perhaps, to torsional stresses accompanying the shearing.

The felsite dikes range in size up to 100 feet or more, and they can be traced in some instances for a good fraction of a mile; but the correlation of individual outcrops is often difficult because of marked irregularities of form and trend. As described by Dr. Bascom, the felsite of these dikes is mainly either densely compact or, more commonly, inconspicuously porphyritic. In general, and as might naturally be expected, the larger dikes have porphyritic centres and non-porphyritic or compact borders, while the smaller dikes are often non-porphyritic throughout. With few exceptions the peripheral portions of the dikes exhibit more or less distinct, and often very marked, fluidal structure parallel with the walls, and the smaller dikes may be characterized by the fluxion lamination through their entire thickness. The

large dikes, also, are usually dark red or purple in the middle portion and greenish gray along the borders, while the small dikes are commonly gray across the entire section. It appears probable that the normal original color of the felsite was gray; that it was subsequently reddened by oxidation, and later bleached by deoxidation and leaching along the borders. The greenish color of the periphery is, however, according to Dr. Bascom's observations, to be connected, in most cases, at least, with a more or less marked epidotization, often followed by hydration and the development of pinite; and not infrequently a border of nearly pure, soft, green pinite has resulted.

Pre-Carboniferous Effusives

Effusive Felsite or Normal Aporhyolite. — The acid effusions of the vents described in the preceding sections, and doubtless of other vents still entirely concealed by the effusives, probably constitute for the Neponset Valley a more or less continuous sheet of lava, chronologically and stratigraphically intermediate between the denuded surface of the batholite and the Carboniferous sediments, and distinctly unconformable in its relations to both. The petrographic and chemical characters of the effusive felsites have been fully described by Dr. Bascom. The original textural variations are most notable, including compact, fluidal, spherulitic, and clastic forms. Although the surface exposures are numerous and instructive, by far the most complete section of the felsites was that afforded temporarily during the construction of the Stony Brook-Neponset tunnel, nearly a mile long, of the Highlevel Sewer. This shows the felsites resting upon both the normal and fine granites at points remote from the nearest surface exposures of these rocks. The flow structure of the felsites, originally horizontal, is now everywhere highly inclined and chiefly vertical, showing that the plication of the Carboniferous sediments was shared by their volcanic floor. As to the original or normal thickness of the acid effusives of the Neponset Valley we have no reliable data, but it was quite certainly to be measured by hundreds and probably not by thousands of feet.

Carboniferous Volcanics

The volcanic rocks definitely known to be contemporaneous with the Carboniferous conglomerate of the Neponset Valley include a moderately acid type — trachyte — and a moderately basic type — andesite.

The andesite largely predominates; but the trachyte is, in the main, at least, the older, and may perhaps be regarded as in some sense a transition type between the felsite and andesite.

Apotrachyte. — As described by Dr. Bascom, this is a coarsely and profusely porphyritic rock of highly feldspathic composition, with albite as the predominating feldspar. Dr. Bascom shows that the chemical analysis of this rock confirms its classification as a soda-trachyte in which diopside must have been an original constituent; or, having regard for its present altered condition, it may be more precisely defined as a soda-apotrachyte. This rock has been recognized as forming one small flow conformably interbedded with the conglomerates of the Central Avenue district in Milton, and a probable vent, in part of agglomeratic structure, on the New England railroad north of River Street, Hyde Park. The latter occurrence was intersected and more fully exposed by the Stony Brook-Neponset tunnel.

Apoandesite. — This important volcanic is described by Dr. Bascom as an aphanitic rock of dark purplish and greenish tints, in which the original constituents are mainly altered to calcite, chlorite, epidote, quartz, and other secondary species. The microstructure is commonly trachytic and inconspicuously fluidal and porphyritic, and the effusive phases are often amygdaloidal or clastic. The distinguishing feature chemically, as for the trachyte, is found in the high percentage of soda; and the extensive mineralogic alteration, without obliteration of original structures, makes this, therefore, a normal soda-apoandesite.

In areal extent and structural value the Carboniferous andesite is comparable with the pre-Carboniferous felsite, and like the felsite it is found in the three general modes of occurrence — necks, dikes, and flows. The bedded lavas, both acid and basic, of the Neponset Valley are believed to be exclusively contemporaneous.

The andesite dikes are very numerous, and they are found in all parts of the complex, cutting the successive zones of the batholite and its cover of acid lava (felsite), and cutting also the acid dikes of various types, including the porphyry dikes and the necks, stocks, and dikes of felsite. In distribution, trend, form, and size they are comparable with the felsite dikes, and the profusion of the basic dikes clearly indicates a very general and extensive fissuring of the subcrust during the subsidence which permitted the deposition of the Carboniferous conglomerate.

It is not improbable that some of the andesite dikes have formed

effective vents. But of unequivocal or normal necks there are no indications in the sedentary zones of the batholite or in the vicinity of the felsite necks; but they are to be found farther east in the effusive felsites, the clearest examples occurring on either side of the Neponset River, in the Mattapan district of Dorchester and the Columbine district of Milton. These vents are decidedly elongated or fissure-like; but they are readily distinguished from the andesite dikes by even greater irregularity of outline, and especially by the heterogeneity of structure and the prevalence of coarsely clastic or agglomeratic lava. The evidence is quite as clear as for the dikes that the andesite is younger than the effusive felsites.

The andesite flows, like the dikes, are chiefly aphanitic, but embrace also amygdaloidal and scoriaceous forms; and in the western part of the field especially bedded tuff and agglomerate, the product probably of explosive submarine eruptions, are prominently developed. The contemporaneous relation of the effusive andesite and the conglomerate is especially clear for these fragmental varieties, but hardly less so for the regularly interbedded flows in the Central Avenue and other parts of the field. The transverse sections of individual flows are, in some instances, very instructive, showing a normal gradation upward from densely aphanitic to amygdaloidal and scoriaceous forms of lava.

Diabase Dikes

As previously intimated, the diabase dikes of this area, as of the Boston Basin generally, are referable to two distinct series — distinct in age, trend, and lithologic character. We may properly emphasize the chronologic distinction as of greatest geologic significance by designating these two series, provisionally, the Carboniferous and the Triassic. Evidently the diabase dikes are not related in origin or composition to any of the other igneous rocks of the district, and in size, regularity, and continuity the two systems are essentially similar and normal.

Carboniferous Diabase Dikes. — The normal trend of the numerous dikes of this series is approximately east-west, and they rarely vary more than thirty degrees from the normal. Although commonly approximately vertical, they are more likely than the Triassic dikes to exhibit a distinct hade, especially in the sedimentary terranes, the manifest tendency being to conform with the strike joints of the enclosing formation. In other words, these are longitudinal dikes, traversing

a series of unsymmetric folds and sympathizing in attitude with the tension planes of the flexures, having been developed during a period of folding and strike or thrust faulting. In the dikes of this series transverse columnar jointing is rarely distinctly developed. Lithologically they are rather fine-grained greenstones, the original or normal constituents having suffered extensive chloritization and epidotization, in consequence of which the diabase is somewhat immune to kaolinization and to be reckoned among the more resistant rocks of the region.

Triassic Diabase Dikes. — The rather infrequent dikes of this series adhere very closely to a north-south trend and vertical attitude, a hade of even a few degrees being very unusual. Their relation to the general geological structure of the region is distinctly transverse, and evidently they date from a period of gravity faulting without folding, such as the Triassic is known to have been. Transverse columnar jointing is commonly well developed, the greenstone alteration is wanting, and the rock yields readily to kaolinization, the tendency to pass by spheroidal weathering to a rusty brown earth being a marked feature of this diabase.

A STUDY OF A SINGLE-PHASE SERIES MOTOR

By GEORGE I. RHODES, S.B.

In the spring of 1905 Mr. E. G. Schmeisser and the writer tested a single-phase series motor of the Lamme type, built by the Westinghouse Electric and Manufacturing Company, the tests being carried on in the Augustus Lowell Laboratories of Electrical Engineering at the Massachusetts Institute of Technology. The motor is a 4-pole, 200-volt, 25-cycle machine, delivering 5-brake horse power at a speed of 1,200 revolutions per minute, the full load current being 32 amperes; and it is furnished with a starting and reversing rheostat of the type used with direct current motors of a similar size (Figure 1). The motor is compactly built and of the semi-enclosed type, occupying

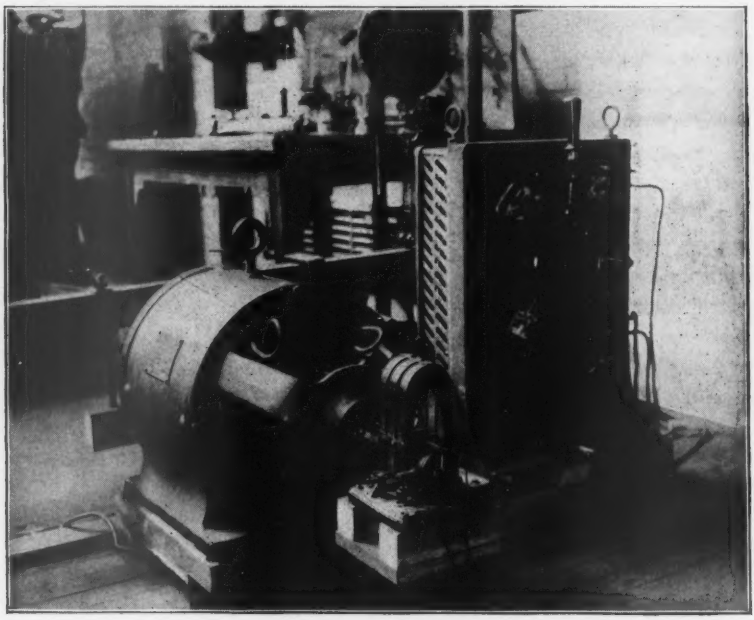

Fig. 1. — Motor and Starting Rheostat

a floor space of 16 x 32½ inches. The construction of the field frame is shown in Figure 2.

The four field coils of twenty-three turns each are wound on forms so as to occupy a minimum space. They are connected in series and have a hot resistance of about 0.12 ohm. The impedance at twenty-five cycles is about 3.5 ohms, decreasing slightly with an increase of load as the saturation of the magnetic circuit is approached.

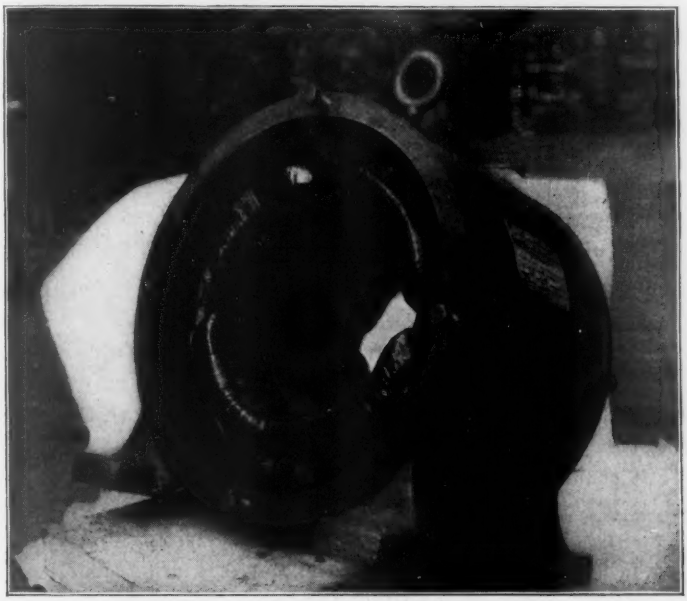

FIG. 2.—FIELD FRAME

The pole faces are each cut with five slots parallel with the shaft, through which are wound the compensating coils, twenty turns per pole. These coils are permanently connected in series with the armature. The armature (Figure 3) is 8⅜ inches in diameter, allowing an air gap of ⅛ of an inch. The winding is in forty-one slots, and leads are brought out to 123 commutator segments, allowing a drop of about seven volts per segment. The total hot resistance of the armature circuit is about 0.40 ohm, and the impedance is about 0.53 ohm, showing that the reactance of the circuit must be less than the resistance. The

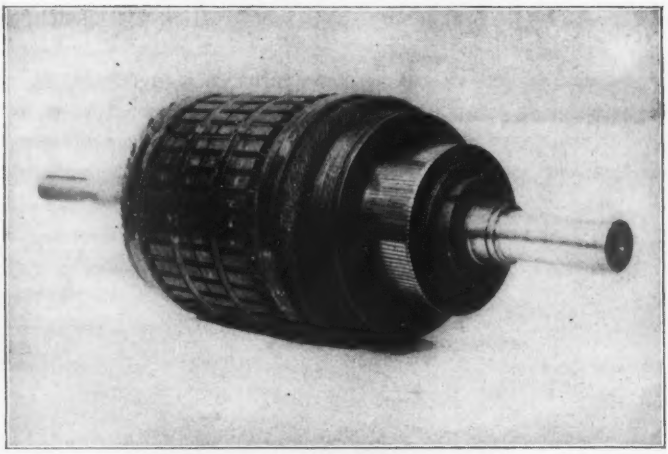

FIG. 3.—ARMATURE

brushes are $\frac{1}{4}$ x $1\frac{1}{2}$ inches, their thickness being less than the width of two commutator segments.

The tests conducted on this motor were primarily with the object of determining its behavior under various conditions of load and voltage, both on alternating and direct current. Sufficient data were taken to give all of the usual motor curves (Figures 4 and 5).

The commercial importance of rise of temperature in any electrical machine led us first to make heat runs at various loads, both on direct and alternating current. The heating was determined by means of copper-nickel thermo-electric couples in the armature and fields. The hot junctions were placed so that they gave indications agreeing very closely with measurements by a mercury thermometer, and having the further advantage of allowing readings to be taken with a very short shut-down of from five to ten seconds. The cold junctions were placed in an oil bath whose temperature was taken by a mercurial thermometer. The curves thus taken under practically continuous operation were very smooth, the points not varying more than one degree from a true curve. From these runs there was deduced the curve given in Figure 5, which shows the time necessary under various loads for the temperature of the motor to rise 50° C. above that of the room. At all loads the motor ran much cooler on direct current than on alternating, the final rise of temperature at full load current being but 35° C.

in the one case and 60° C. in the other. On a heating basis, the motor could easily be rated as a 9-horse power direct current motor.

The armature and the field ran within a very few degrees of each other when the machine was operated on alternating current at full

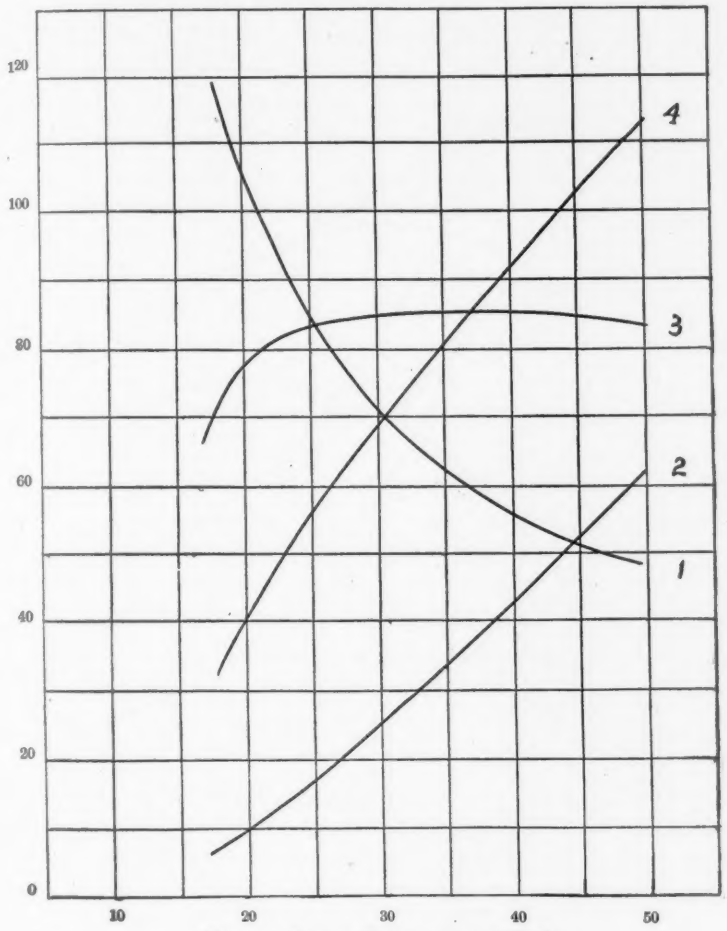

FIG. 4. — CURVES TAKEN AT 200 V D. C.

1. Ordinates = Speed, R. P. M. ÷ 10.
2. Ordinates = Torque pounds feet.
3. Ordinates = Efficiency %.
4. Ordinates = Output H. P. × 10.
   Abscissæ = Amperes input.

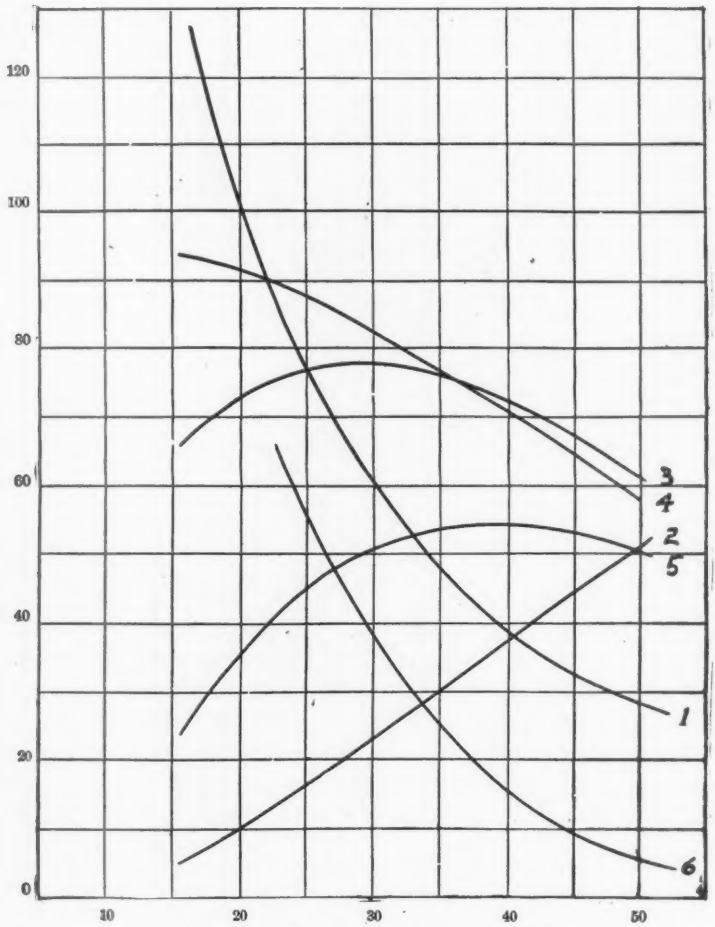

FIG. 5. — CURVES TAKEN AT 200 ~ 25 ~

1. Ordinates = Speed, R. P. M. ÷ 10.
2. Ordinates = Torque pounds feet.
3. Ordinates = Efficiency %.
4. Ordinates = Power factor %.
5. Ordinates = Output H. P. × 10.
6. Ordinates = Time to rise 50° hours × 10.
   Abscissæ = Amperes input.

load, but at overloads the armature heats up much more rapidly than the fields. The motor has a rather limited overload capacity on account of this excessive heating of the armature coils, which is due

to the short circuit current at commutation. This heating is, of course, local, but it is very marked and probably much greater than shown on the heat runs. In an attempt to find out more about this heating, a junction was placed between two coils at the end of the armature, and it was found that a run of half an hour at a load of 50 amperes was sufficient to produce a rise in temperature of as much as 100° C.

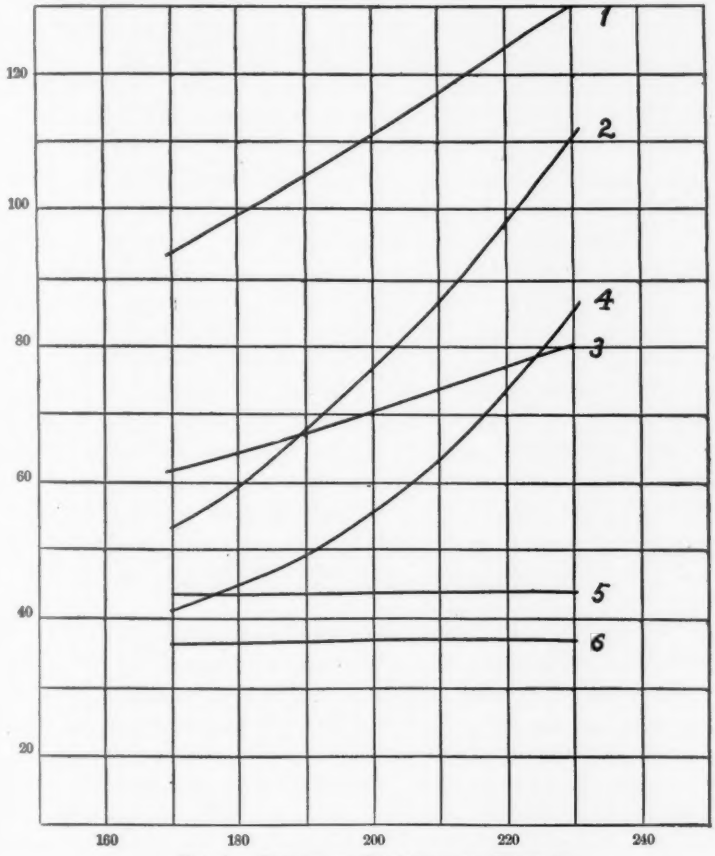

FIG. 6. — EFFECT OF VARIATION OF VOLTAGE

1. Ordinates = Speed, R. P. M. ÷ 10, 40^A D. C.
2. Ordinates = Speed, R. P. M. ÷ 10, 40^A A. C.
3. Ordinates = Power factor, 40^A A. C.
4. Ordinates = Maximum output H. P. × 10, A. C.
5. Ordinates = Torque pounds feet, 40^A D. C.
6. Ordinates = Torque pounds feet, 40^A A. C.

Abscissæ = Impressed volts.

The other curves given in Figures 4, 5, 6, and 7 will serve as a basis of comparison of the action of the motor on direct and alternating current. The speed and torque curves are of the types characteristic of the direct current series motor, but the effect of the alternating current is quite well marked. The torque increases in both sets of curves at a greater rate than the current, but when the motor is run on alternating current the torque is lower at all loads than when operated on direct current. The percentage difference is small at light loads, but it increases to about 20 per cent. at 50 amperes. The impressed voltage has little effect on the torque (Figure 6), hence the motor will start satisfactorily as a single-phase machine under such low voltages as are experienced in railway work.

The alternating current and the direct current speed curves are similar, but the alternating current curve is much steeper. At light loads it makes little difference in speed whether the motor is operating on direct or alternating current, but at loads of 50 amperes the speed on a twenty-five cycle circuit is about 40 per cent. below that on a direct current circuit. The variation of speed due to changes of voltage (Figure 6) is much greater on alternating than on direct current. The curves approach each other as the voltage increases, the speed on alternating current being always the lower. The speed at 170 volts, twenty-five cycles, is 40 per cent. below that on direct current at the same voltage, and less than 15 per cent. lower at 230 volts. The large impedance drop in the field coils of the single-phase motor, as compared with the relatively small resistance drop in the coils of a direct current motor, is largely responsible for this difference in speed.

A comparison of the speed and torque characteristics shows that the motor would be better for railway work if operated on direct current; but as such a motor it is probably better than commercial motors of the same size, and since there is no data at hand for direct current motors of small size we cannot tell whether or not the alternating current characteristics of this motor are as good as are usually obtained in direct current practice. The single-phase motor will probably not give such a rapid train acceleration as the direct current motor on account of the low torque with large currents, but the ultimate maximum speed will be about the same in both cases. This condition should have an important influence on the use of alternating current for local or suburban traffic where stops are frequent.

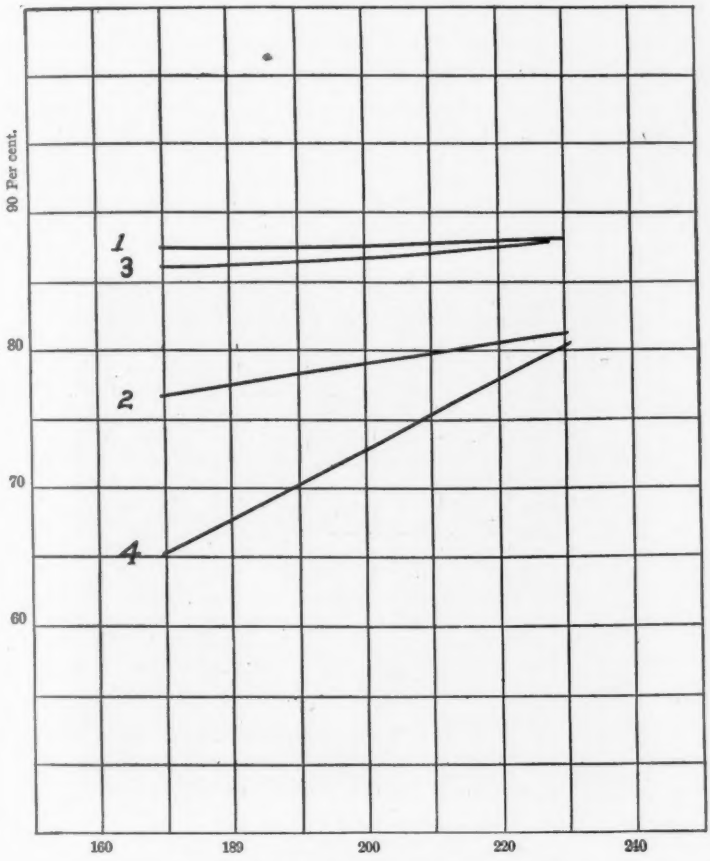

FIG. 7. — EFFECT OF VARIATION OF VOLTAGE

1. Ordinates = Maximum efficiency D. C.
2. Ordinates = Maximum efficiency A. C.
3. Ordinates = Efficiency at 40^A D. C.
4. Ordinates = Efficiency at 40^A A. C.

Abscissæ = Impressed volts.

The running efficiency is very good for a motor of its size, being between 75 per cent. and 80 per cent. with alternating current and about 85 per cent. with direct current. The maximum value increases slightly with the voltage. The impressed electro-motive force has a still more important effect on the shape of the efficiency curves. At low voltages with alternating current the efficiency reaches its maximum

at light loads and falls off quite rapidly, while at high voltages the high efficiency is sustained over much wider variations of load. At 200 volts the efficiency begins to fall off at about 10 per cent. overload, but at 230 volts there is no material drop even at 50 amperes. The curves in Figure 7 show the effect on efficiency, of voltage variation.

The curves of power factor (Figure 5) are all very nearly straight lines, dropping from about 90 per cent. at small loads to a low value, largely dependent on the impressed voltage at large overloads. The

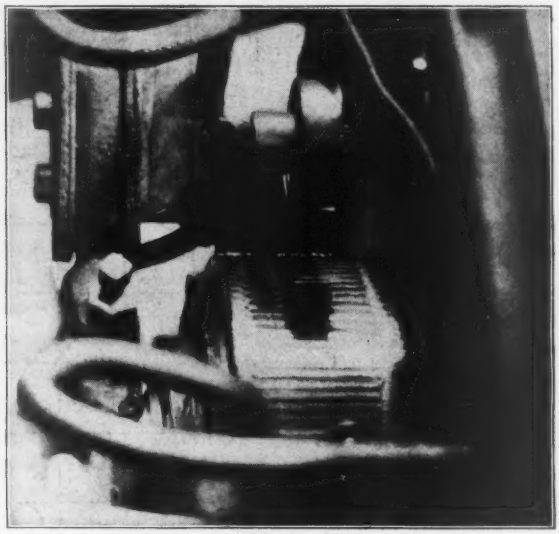

FIG. 8. — SPARKING AT FULL LOAD
Exposure, 1½ seconds

curve in Figure 6 shows the effect of voltage on the power factor at 40 amperes. It rises from 62 per cent. at 170 volts to 80 per cent. at 230 volts. Results such as these are to be expected, for at a voltage equal to the impedance drop in the fields the power factor will be very low, as in a transformer at no load. The value of this voltage at 40 amperes is about 140 volts. The power factor of the armature is very nearly unity at all loads on account of the very low reactance voltage.

The motor was run on one phase of a 75-kilowatt three-phase generator of recent construction, and the voltage fluctuations were very large on all three lines when the load was changed in any considerable degree. On starting the voltage dropped to a very low value.

The commutation of single-phase motors has given rise to much discussion. With reference to this point the motor under test was quite unsatisfactory. No matter how carefully the brushes were fitted the commutation was quite bad at all loads and exceedingly vicious at a load of 50 amperes. The longer the motor was run the worse the sparking. A fairly good idea of the commutation at full load can be obtained from Figure 8, which was given one and one-half seconds exposure. Figure 9, taken under the same conditions, was given

FIG. 9. — SPARKING AT FULL LOAD
Exposure, $\frac{1}{60}$ second

an exposure of one-sixtieth of a second, and shows the size of the spark as each commutator segment leaves the tip of the brush.

There was less damage done to the commutator than might have been expected, but the brushes were badly burned, especially on the trailing edge. The motor operated sparklessly on direct current at all loads, and after a long run the brushes fitted so well that sparking was at first small, even on alternating current. The commutator and brushes ran very hot at the slightest overload.

The position of the brushes affected commutation in much the same way as in a direct current motor; that is, the sparking was improved if the brushes were given a slight backward lead. It would

be inferred from this condition that the troubles of commutation of this motor are not wholly due to the short circuit current, but also to the running current, and that it would be merely a question of design to improve the motor in this respect.

This movement of the brushes led to the very interesting discovery that the position of the plane of commutation had a considerable influence over all the general operating characteristics of the motor. The torque was slightly raised at all loads by a backward movement of the brushes. At all loads the speed was decreased considerably by a forward lead and increased by a backward lead. The output for a given current, and hence the power factor, was decreased or increased according as the brushes were moved in or against the direction of rotation. The power factor could be improved several per cent. and the maximum output materially increased by a proper adjustment of the brushes. This improvement lasted only so long as the motor was run in one direction, for on reversal all of the characteristics became worse than ever.

As a commercial motor this particular machine is not a success on account of the small overload capacity and the continual care that must be taken of the brushes to make them commutate in a satisfactory manner. The working characteristics are quite suitable for most of the uses to which a direct current series motor is put, but the commutation needs to be much improved for successful commercial operation.

A NOTE ON THE CALCULATION OF THE ARMATURE REACTION OF ALTERNATORS

By WALDO V. LYON, S.B.

The armature reaction of an alternating-current generator influences the regulation more, probably, than any other one characteristic. It is fundamentally a magneto-motive force produced by the action of the alternating currents in the armature coils, and its general effect is to alter the flux distribution in the air gap as produced by the direct-current field when the machine is running on open circuit.

The object of this discussion is to show the assumptions that must be made to calculate the armature reaction as it is ordinarily done. On the score of simplicity a single-phase alternator will first be considered, and then the equations will be extended to a three-phase machine.

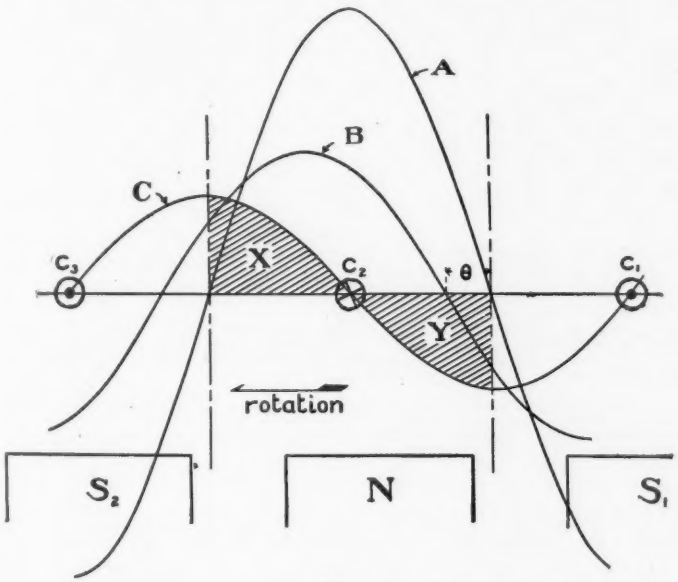

Fig. 1

Figure 1 represents the development of the air gap of an alternator, having a concentrated winding. Three poles, S_1, N, and S_2, and two armature coils, C_1C_2 and C_2C_3, are shown. The convention of the dots (·) and crosses (×) signifies that the current flows in opposite directions. In order that the following discussion may apply to a definite condition, the machine will be considered as under full load, although it is perfectly general for all loads, if the same assumptions be made.

The first assumption will be that the wave of electro-motive force is sinusoidal. This electro-motive force induced in the conductors C_1, C_2, etc., is proportional to the rate of cutting of magnetic lines, and, since the speed is uniform, it is proportional to the flux density where the conductors cut the lines of force. Hence it at once follows that the curve representing the resultant flux density must be sinusoidal, and also that it must be in phase with the wave of electro-motive force. It is usually more convenient, however, to use the coil electro-motive force in alternator calculations, and in this case, since the position of the coil is marked by its mid-point, the E. M. F. wave will lag ninety electrical degrees with respect to the curve of flux distribution, if we adopt the convention that the E. M. F. of the coil is from C_1 to C_2, *i.e.*, $V_{C_1} - V_{C_2}$. This distinction should be borne in mind In the present case, however, the curve relates to the armature conductors, and is thus in phase with the flux distribution. The current will lag with respect to the induced electro-motive force by an amount depending on the constants of the machine and those of the external circuit. For a capacity load this lag may be negative, that is, a leading current will flow.

A second assumption will be made that the flux distribution due to the current flowing in the armature coils would be sinusoidal if it existed as a real quantity.

These two assumptions are tacitly made in every vector solution of the problem.

It seems somewhat more logical to deal with the ampere-turns as representing the magneto-motive forces, rather than with the fluxes produced by them, and in this case another assumption will have to be made.

The fundamental equation for the magnetic circuit is:—

$$NI = \frac{10}{4\pi}\phi\left[\frac{v_1 l_1}{\mu_1 a_1} + \frac{v_2 l_2}{\mu_2 a_2} + \ldots + \frac{2l_g}{A_g}\right].$$

For some particular point and path of flux passing through it the equation takes the differential form: —

$$\frac{d}{dx}(NI) = \frac{10}{4\pi}\frac{d\phi}{dx}\left[\int\frac{v_1}{\mu_1}\frac{dl_1}{da_1} + \cdots \int\frac{2dl_g}{da_g}\right].$$

In this equation $\frac{d}{dx}(NI)$ is the space variation of the ampere-turns, and $\frac{d\phi}{dx}$ is the space variation of the flux, that is, the flux density.

Now if the expression in the brackets [ ] is assumed constant for any and all paths of the flux, that is, if the reluctance of the magnetic circuit is constant for all paths, then the distribution of ampere-turns will be in effect sinusoidal, since it has been shown that with a sine E. M. F. the curve of flux density $\left(\frac{d\phi}{dx}\right)$ must be sinusoidal. This assumption of constant magnetic reluctance is more nearly true of the magnetic circuit in which the magneto-motive force of the resultant field acts, than of the circuit connected with the magneto-motive force of the armature. The effect of the armature slots is to produce additional reluctance at these points in the field circuit. In the case of the armature, the same effect is produced by the spaces between adjacent field poles, except that it is greatly magnified. The spread of lines at the pole tips, which is necessary under the assumption of sinusoidal distribution, would affect the reluctance of paths passing through these points. But it will be assumed that the distribution of ampere turns on both field and armature is sinusoidal. This assumption is also made when the magneto-motive forces are represented as vectors in the graphical solution of the problem.

In the following proof no leakage factors are assumed to be applied to the armature and field fluxes, as it is simpler to leave their consideration until the final result is obtained. This point is considered in the note on "The Relation of Armature Reaction to Armature Reactance."

The curves of electro-motive force, current, and distribution of ampere-turns are given in Figure 1. Curves A and B are stationary, and their ordinates represent the instantaneous values of the induced voltage and current for the progressive positions of the armature conductors. It will be noticed that the current lags with respect to the induced potential by an electrical angle θ, which is positive in the direction of motion. To the proper scales curve A represents either

resultant flux, distribution of resultant ampere-turns, or induced electromotive force. Curve C represents the distribution of ampere-turns due to the armature conductors. Its amplitude is determined by the instantaneous value of the armature current, and it is evident that its nodes must coincide with the position of the armature conductors, and hence it will move synchronously with them.

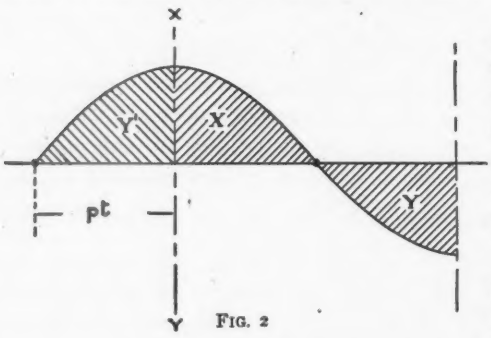

FIG. 2

It is readily seen that the effective ampere-turns on the armature which act directly against the field pole N are represented by the algebraic sum of the shaded areas X and Y, Y being considered as positive. Inspection of Figure 2 shows that the algebraic sum of X and Y is equal to the negative of the numerical difference of X and Y′, since the distance between the conductors is equal to the distance between adjacent nodes of the resultant flux wave. Thus the same result is obtained for the net ampere-turns acting against N if the line XY be assumed to move at the same speed as the armature conductors but in the opposite direction; that is, to the right. It will now be shown that the effective ampere-turns on the armature acting against the field pole N vary as the cosine of the angular displacement of the armature conductor from the node of the curve of the resultant flux distribution.

$$X + Y = Y' - X.$$

This may be written in the form:—

$$X + Y = 2Y' - (X + Y').$$

Let i be the instantaneous value of the current for the given position of the conductors. This may be obtained from the current curve in Figure 1. Then the total instantaneous ampere-turns represented by the area $X + Y'$ will be $\frac{1}{2}(Ni)$, when N is the number of series conductors per pole. This relationship is readily shown to hold if each conductor of the several coils is divided into two portions carrying equal currents, as in Figure 3. The magneto-motive force, as

represented by $X + Y'$, is produced by the coil $C_1'' C_2'$. This coil has as many turns as there are conductors per pole, but it carries only one-half the total current in each real conductor.

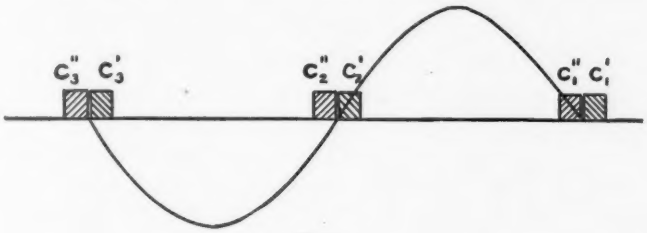

FIG. 3

Let $\frac{1}{2}(Ni)_0$ be the maximum value of the ampere-turns distribution for the particular instant considered. Then the equation of the curve will be:—

$$\tfrac{1}{2}(Ni)_{pt} = \tfrac{1}{2}(Ni)_0 \sin pt.$$

Then the total ampere-turns will be given by:—

$$\tfrac{1}{2}(Ni) = \int_0^{\pi} \tfrac{1}{2}(Ni)_{pt}\, d(pt) = (Ni)_0.$$

Hence the total instantaneous ampere-turns as represented by the area $(X + Y')$ are twice the numerical value of the maximum density of the ampere-turns distribution.

That is:—

$$(X + Y') = (Ni)_0.$$

$$2Y' = 2\int_0^{pt} \tfrac{1}{2}(Ni)_0 \sin pt\, d(pt) = (Ni)_0\,[1 - \cos pt].$$

$$\therefore (Y' - X) = -(Ni)_0 \cos pt.$$

Therefore the net ampere-turns acting against the single pole N for any particular instant are given by:—

$$-\tfrac{1}{2}(Ni)\cos pt.$$

N is the number of conductors per pole, i is the instantaneous value of the current, and pt is the angular displacement of the conductor from the assumed zero. It should be observed that the net armature magneto-motive force for any particular instant produces the same effect on the resultant field, whether the conductors are opposite a north or a south pole. The value of this cosine function, however, changes its sign when pt is increased by $n\pi$ (where n is any odd

integer). Therefore the complete cosine function should be in the form $-\frac{1}{2}(Ni)\cos(pt + n\pi)$ where n is zero when the conductors are under a north pole, and is one when they are under a south pole.

$$i = I \sin(pt - \theta).$$

$$\therefore A_1 = -\tfrac{1}{2} NI \sin(pt - \theta)\cos(pt + n\pi).$$

A_1 is the instantaneous net magneto-motive force of the armature which acts directly against the magneto-motive force of one pole.

The discussion of this equation will be confined to the effect on the north pole N, since the same result is produced against every pole. Inspection shows that the curve crosses the axis of abscissæ at the points:—

$$pt = \theta \quad \text{and} \quad pt = \frac{\pi}{2}.$$

The maximum and minimum values of the equation are found by placing the first differential equal to zero. These values occur at the points:—

$$pt = \frac{\theta}{2} + \frac{\pi}{4} \quad \text{and} \quad pt = \frac{\theta}{2} + \frac{3\pi}{4}.$$

This shows that the maximum and minimum points are 90° apart and are halfway between the nodes. Substitution in the original equation gives the following maximum values of A:—

$$pt = \frac{\theta}{2} + \frac{\pi}{4} \qquad A_1' = -\frac{NI}{2}\left[\frac{1 - \sin\theta}{2}\right].$$

$$pt = \frac{\theta}{2} + \frac{3\pi}{4} \qquad A_1'' = -\frac{NI}{2}\left[-\left(\frac{1 + \sin\theta}{2}\right)\right].$$

The relative forms and magnitudes of the curves are shown in Figure 4. The convention adopted is that the net armature M. M. F. is positive when opposed to that of the resultant field, and also that the lag angle is positive in the direction of rotation. It should be remembered that the ordinates of these curves merely represent the algebraic value of the net magneto-motive force of the armature which is acting directly against the magneto-motive force of one field-spool. It is seen that when θ is negative the average net effect of the armature reaction is to increase the impressed field, and when θ is positive the field is diminished. Therefore it is said that a leading current aids the field and a lagging current demagnetizes it.

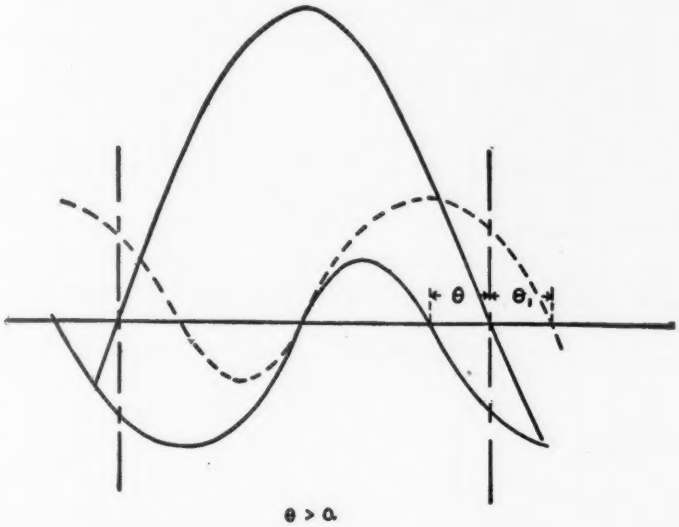

FIG. 4

The average value of the armature reaction is found as follows:—

$$\text{Average } A_1 = -\frac{1}{T}\int_0^T \tfrac{1}{2} NI \sin(pt - \theta)\cos pt\, dt = \tfrac{1}{4} NI \sin\theta.$$

The armature reaction is generally given per pair of poles, and the R. M. S. value of the current substituted for the maximum value. The equation is then written:—

$$A_1 = .707\, NI \sin\theta.$$

This result proves the deductions previously made as to the effect of the lag angle θ.

It will be remembered that there were two broad assumptions made. For all paths of the flux the reluctances of the magnetic circuit of the resultant field and of the armature reaction are constant; and the distribution of the magneto-motive force of the resultant field, and the instantaneous distribution of the armature reaction are sinusoidal. The effect of the armature reaction is to cause an effective flux wave of double frequency. But by supposition the resultant flux wave is sinusoidal, and from this it follows that the flux wave on open circuit must be compounded of a sine wave and one of double

frequency. This conclusion is obviously absurd, and the probable effect is that the flux wave under load conditions is not sinusoidal but is periodically distorted by the armature reaction. This method of using the net effect of the armature reaction has also the disadvantage that it neglects in a great part the distorting effect on the field.

With polyphase alternators the effective armature reaction is of constant value throughout the cycle. The following proof is for a three-phase machine.

Let N equal the total number of turns between adjacent north poles. $\frac{N}{3}$ = turns per phase.

$$i_1 = I \sin (pt - \theta).$$
$$i_2 = I \sin (pt - \theta - 120°).$$
$$i_3 = I \sin (pt - \theta - 240°).$$

Therefore:—

$$a_1 = -\frac{NI}{3} \sin (pt - \theta) \cos pt.$$
$$a_2 = -\frac{NI}{3} \sin (pt - \theta - 120°) \cos (pt - 120°).$$
$$a_3 = -\frac{NI}{3} \sin (pt - \theta - 240°) \cos (pt - 240°).$$

The effect of each phase is the same as the total reaction of a single-phase alternator, but the phases are displaced by 120° from each other in the three-phase generator, and the total reaction is now the sum of the three reactions.

$$a_1 + a_2 + a_3 = A = -\frac{NI}{3} [\sin (pt - \theta) \cos pt +$$
$$\sin (pt - \theta - 120°) \cos (pt - 120°) +$$
$$\sin (pt - \theta - 240°) \cos (pt - 240°)].$$

This reduces to $$A = \frac{NI_{max.}}{3} \frac{3}{2} \sin \theta.$$

$\therefore$ as before, $$A = .707\, NI \sin \theta.$$

Therefore the net effect of the armature reaction of a three-phase generator is constant, and the effective distribution of ampere turns may be assumed to vary sinusoidally and to have a constant amplitude. From this it follows that the distribution of flux on open circuit must be sinusoidal, and the original assumptions are not violated as in the case of a single-phase generator.

The effect of wide slots is to cause a path of increased reluctance to sweep across the pole pieces, and hence make a periodic variation in the flux distribution. This would tend to cause higher harmonics in the E. M. F. wave. Wide slots would also vary the distribution of the magneto-motive force due to the armature. In like manner the effect of the spaces between adjacent poles is to cause a periodic variation in the reluctance of the magnetic circuit on which the armature reaction acts. Since these spaces are, as a rule, very large, the distortion of the armature flux wave is probably extreme.

The effect of the armature reaction, which is by nature a magneto-motive force, should be in phase with the armature current that produces it. As its value was deduced, it was made directly to oppose the resultant flux, and was hence in opposition to it.

From Figure 5 it is seen that if $[.707\,NI \sin\theta]$ represents the armature reaction as in opposition to the resultant field, then $[.707\,NI]$ is the reaction as in phase with the armature current.

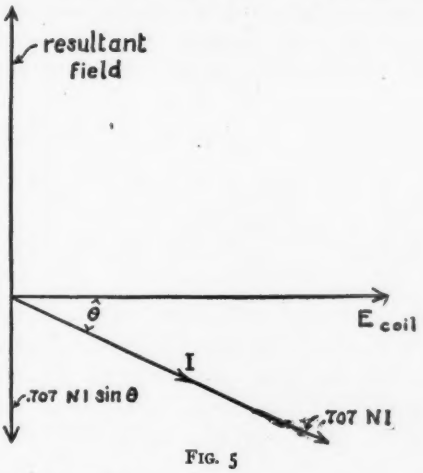

FIG. 5

If N is the total number of conductors on the armature and P the number of poles, then it follows:—

$$A = .707\,\frac{NI}{P}.$$

This is the usual expression for the value of armature reaction.

RELATION BETWEEN ARMATURE REACTION AND ARMATURE REACTANCE

The two general equations of flux relationship for the armature are:—

$$\phi_a' = 2\,NL\,\phi_1\,I.$$

$$\phi_a = \frac{4\pi}{10}\,NI\,Z.$$

The first equation gives the leakage lines per phase as they are usually calculated. N represents the number of turns per phase, L the length of imbedded conductor, ϕ_1 the leakage flux per unit length of conductor and per ampere, and I is the armature current. It assumes that there is no leakage around the ends of the coils. This is very nearly true, since the path of this leakage flux contains practically no iron.

The second equation gives the total flux that would be produced by NI ampere-turns acting on a magnetic circuit of permeance Z. This equation also deals with the flux per phase, and so the results obtained from the combination of these two equations are applicable to a K phase machine.

The leakage coefficient for the armature is then given by:—

$$v_a = \frac{\phi_a}{\phi_a - \phi_a'} = \frac{Z}{Z - \frac{5}{\pi} L\phi_1}$$

$$\therefore Z = \frac{\frac{5}{\pi} L\phi_1 v_a}{v_a - 1} \qquad (1)$$

As in calculating the armature reaction, the reluctance in the path of the resultant flux and of the armature flux will be considered the same, but that component of the resultant flux which is due to the direct field will be substituted. This is equivalent to considering the condition on open circuit.

Then it follows:—

$$\phi_f = \frac{4\pi}{10}\left(\frac{NI}{v}\right)_f Z.$$

The useful ampere-turns on the field are represented by $\left(\frac{NI}{v}\right)_f$, and v is the leakage coefficient for the field alone.

$$\therefore Z = \frac{\phi_f}{\frac{4\pi}{10}\left(\frac{NI}{v}\right)_f} \qquad (2)$$

Equate (1) and (2).

$$\therefore \frac{L\phi_1 v_a}{v_a - 1} = \frac{\phi_f}{2\left(\frac{NI}{v}\right)_f} \qquad (3)$$

The general equation for induced electro-motive force, which applies to this condition of open circuit, is given by :—

$$e = 4f\,Nn\,\phi_f\,10^{-8}.$$

In this n represents the number of cycles per second, and f is the form factor.

If the value of ϕ_f obtained from this equation is substituted in equation (3), the latter can then be written in the form :—

$$\frac{10^8}{8\,Nnf}\,\frac{e}{\left(\frac{NI}{v}\right)_f} = L\phi_1\,\frac{v_a}{v_a - 1}. \qquad (4)$$

The armature reactance is usually calculated from the following formula :—

$$x = 2\,\pi n S_1 \phi_1 L N_1^2\,10^{-8}.$$

The number of slots per phase is represented by S_1 and the series conductors in each slot by N_1. In calculating the reactance in this manner, it is assumed that all of the leakage lines are linked with all of the conductors of the particular slot. This may not be strictly true with very deep slots. It will be observed that :—

$$\frac{S_1 N_1}{2} = N.$$

Equation (4) may now be written as follows :—

$$\frac{v_a}{v_a - 1} = \frac{\pi N_1}{2fx}\,\frac{e}{\left(\frac{NI}{v}\right)_f}. \qquad (5)$$

In considering this problem we have assumed that the wave of electro-motive force was sinusoidal, and under this condition $f = 1.11$. The ratio $\frac{e}{(NI)_f}$ may be obtained directly from the open circuit characteristic as soon as the turns per pair of poles are known ; let it be represented by the factor K. K should be found for the point when e is the induced armature voltage under the given load condition.

The solut ı of equation (5) for v_a may be written as follows :—

$$\frac{1}{v_a} = 1 - 0.707\,\frac{x}{N_1 v K}.$$

Therefore it must follow that the true armature reaction is given by the equation[1]:—

$$A = \left(1 - 0.707 \frac{x}{N_1 v K}\right) 0.707 \frac{NI}{P}. \qquad (6)$$

The only important assumption which might be questioned is that of the equality of the reluctances of the magnetic circuits in which the armature reaction and resultant field act. This assumption was made, however, when the general formula for the armature reaction was deduced, and so it does not seem improper to retain it in this discussion.

Inspection of equation (6) shows that as saturation is approached the armature reaction is probably somewhat reduced in value.

[1] The leakage factor for the field, v, increases slightly as the excitation is increased. For open slot machines saturation affects the leakage lines of the armature but little, since the majority of the reluctance is in the air gap, and thus x is very nearly constant, although it may decrease slightly with high saturation.

BOOK REVIEWS

A Text-Book of Quantitative Chemical Analysis[1]

This book was written primarily as a text-book to meet the needs of the author's own students, and not as a reference book for the experienced analyst, although it covers practically the whole field of quantitative analysis. He claims that the text-books available did not give as thorough and comprehensive a view of the subject as he wished, and he therefore has endeavored to correlate the theoretical and practical sides of the subject in such a way as best to meet the demands of the student. As no two teachers of analytical chemistry will look at the subject from the same point of view, there is sure to be some difference of opinion in regard to the emphasis laid upon the various parts of the subject. This is inevitable and proper; otherwise there would be no new books.

In this book there is nothing essentially new in the way of treatment and very little originality in the method, although the subject as a whole is treated very evenly and clearly. There is much of it, however, which gives the distinct impression of being a compilation rather than the results of experience. Most of the methods described and the apparatus employed are to be found in the standard texts; and, unfortunately, in many cases methods are cited without acknowledgment of their origin. The general omission of references is to be deplored.

There seems to be a considerable lack of experience in what is called the practical side of analytical chemistry. This is especially true with the chapters on analysis of alloys and technical analysis, the latter including the analysis of iron and steel. On page 146, under the determination of phosphorus in bronze, the author recommends the oxidation of the phosphorus with concentrated nitric acid and the collection of the phosphoric acid with the tin as stannic phosphate. In

[1] A Text-Book of Quantitative Chemical Analysis by Gravimetric, Electrolytic, Volumetric, and Gasometric Methods. By J. C. Olsen, Professor of Analytical Chemistry in the Brooklyn Polytechnic Institute. New York: D. Van Nostrand Company, 1904. xix + 513 pp. Price, $4.00.

this particular sample with which the author worked this oxidizing agent might have sufficed, but in most alloys containing this element much more vigorous means have to be taken to get complete oxidation of the phosphorus. In the chapter treating of iron and steel analysis, of which the reviewer believes that for purposes of instruction in rapid, accurate work there can be no better example, the author treats the subject incompletely and unsatisfactorily. Here, again, there is a woeful lack of references to the literature.

The chapters on the balance, including calibration of apparatus, general operations, determination of metals and acids, water analysis, gas and oil analysis, are much more complete and satisfactory, and would serve as an excellent guide.

The author is progressive, inasmuch as he treats of the theoretical side of analytical chemistry as well as the practical side, although not emphasizing particularly interesting cases. This portion of the book is not entirely satisfactory, for the Law of Mass Action is evidently confused with what the author calls the "law of ionization," and the difference between the ion and the atom is not made clear. On page 21 we read, "Acids dissociate, giving the hydrogen *atom* as one ion and the remainder of the acid as the other ion"; again, on page 193, "The molecule of cupric chloride separates into three ions, one of which is the copper *atom*, while the other two are chloride *atoms*." This is carelessness, indeed!

The chapter on stoichiometry is a valuable addition to a text-book of this kind and is very clearly written. There is also an appendix, containing a considerable number of tables useful to any analytical chemist.

Notwithstanding the above criticisms of various parts of the book, the author has made an interesting addition to the literature of analytical chemistry. The weakest part of the book is in not having given due credit for the various methods. An inexperienced reader would give the author more credit than is due him, and would not realize that analytical chemistry is the production of a large number of faithful workers.

HENRY FAY.

The Chemical, Metallurgical, and Mining Society of South Africa[1]

The third volume of the Proceedings of the Chemical, Metallurgical, and Mining Society of South Africa, recently published, covers the proceedings from May, 1902, to June, 1903, and contains the following papers read at the monthly meetings, with complete discussion on each:—

I. Notes on the Analysis of Cyanide Solutions. Andrew F. Crosse (May, 1902).
II. Notes on the Treatment of Slimes by Means of Filter Presses. Clement Dixon (June, 1902).
III. The Smelting and Refining of Zinc-Gold Slimes. E. H. Johnson and W. A. Caldecott (July, 1902).
IV. A Slight Improvement in Extractor Boxes. S. B. Hutt (August, 1902).
V. An Improved Washbottle for Quantitative Work. E. H. Weiskopf (August, 1902).
VI. Residual Products of the Dynamite Factory, and Their Value to the Gold Industry. W. Cullen (August, 1902).
VII. The Thermo-Hyperphoric Process. A. T. Firth (September, 1902).
VIII. Notes on Valuing a Gold Mine. T. Lane Carter (September, 1902).
IX. Notes and Queries. H. T. Durant (September, 1902).
X. The Lead Smelting of Zinc-Gold Slimes. P. S. Tavener (October, 1902).
XI. Notes on Mine Sampling of the Main Reef Series. D. J. Williams (October, 1902).
XII. The Economic Use of Petroleum Oil Gas Furnaces, as Applied to Smelting, Laboratory Work, and Drill Heating. David Laird (October, 1902).
XIII. The Theory of Miss-Fires, and Some Conclusions of Practical Value. E. H. Weiskopf (November, 1902).
XIV. Notes on Commercial Cyanide of Potash. A. Whitby (December, 1902).
XV. Miner's Phthisis: Some Notes and Suggestions. W. Cullen (February, 1903).
XVI. The Regeneration of Working Cyanide Solutions, Where Zinc Precipitation Is Used. Andrew F. Crosse (March, 1903).
XVII. Notes on the Common Practice of Quartz Milling on the Rand. Fraser Alexander (March, 1903).
XVIII. Extraction of Gold from Cyanide House Slimes by a Wet Method. John Fleming (April, 1903).
XIX. An Automatic Sampler for Tailings, Sands, and Slimes. C. H. Pead (April, 1903).
XX. The Refining of Lead Bullion. F. L. Piddington (May, 1903).
XXI. A Few Remarks on Banket Formation. A. R. Sawyer (September, 1894; omitted from Vol. I).

These papers are followed by appendices containing the proceedings of the monthly meetings, a report of the Committee on Cyanide Poisoning, correspondence, obituary notices, and notices of abstracts of articles and papers published elsewhere, classified according to the subject, and also separate indices to authors and subjects.

[1] Proceedings of the Chemical, Metallurgical, and Mining Society of South Africa, III, May, 1902, to June, 1903. Johannesburg (New York: Engineering and Mining Journal, 1905). 17 + 483 pp., 9 pl., 8vo.

Gold Mining in the Black Hills[1]

This is a reissue of a paper read by Professor Hofman before the American Institute of Mining Engineers in 1889, while he was connected with the Dakota School of Mines. The value of the paper is shown by the fact that the leading firm of manufacturers of mining and metallurgical machinery in this country prints it at this date for distribution among its customers.

The Overstrom Concentrator[2]

An attractive pamphlet contains the description of this machine of the Wilfley type, which the firm is putting on the market. The paper contains a full discussion, with illustrations. The diagrammatic colored representation of the separations taking place on the washing table are striking.

Gas-Engine Design[3]

This book avoids the subject-matter usually found in treatises upon gas engines. While others deal with the problems of combustion, with discussions of the various theoretical cycles, and the descriptions of the actual engines, the present volume "is concerned entirely with the quantitative side of design, and treats solely of the forces in and the energy transforming power of the standard mechanism of the exploding gas engine."

The subject-matter falls under three general headings: (1) power, efficiency, economy; (2) forces in the engine due to gas pressure and inertia; and (3) dimensions of the engine parts.

As a foundation for the first chapter the author defines a standard reference diagram "as that indicator card which would result if pure

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[1] Gold Mining in the Black Hills. Hofman, H. O. Milwaukee: Allis-Chalmers Company, 1905.

[2] The Overstrom Concentrator. Milwaukee: Allis-Chalmers Company, 1905.

[3] Gas-Engine Design. By Charles Edward Lucke, Ph.D. New York: The D. Van Nostrand Company, 1905. 254 pp., cl., ill. $3.00.

air passed through the four phases of an ideal cycle (Otto), receiving the same amount of heat per pound of air working as does the pound of air and gas mixture in its combustion." The compression curve starts at 14.7 pounds pressure per square inch and 62° F. This is followed by a study of the properties of various fuels, with tables of heating values, maximum compression to be used with different substances, etc. And then, by a comparison of observed with computed mean effective pressures, a set of diagram factors is deduced, to be used for all common fuels. These data make it possible to compute the dimensions of an engine to furnish any desired power, using any given fuel.

The second division starts with a discussion of actual indicator cards, showing how the shape and area of the card are affected by varying the percentage mixture of gas and air, by piston speed, throttling, and time of firing. This makes it possible for the designer to draw the probable card, and thus construct the probable rotative effect for any fuel. This is followed by the usual mathematical discussion of the effect produced by the inertia of the reciprocating and rotating parts, supplemented by plots of many different inertia curves. This section closes with a comparison of the various ways of balancing the crank pins and connecting rods, followed by a large number of diagrams giving indicator cards, inertia diagrams, and effective or net rotative thrusts for two complete revolutions.

Having determined the general proportions of the engine and the forces exerted in it throughout a complete cycle, the last portion of the book is devoted to the proportioning of the different parts of the engine to make it withstand these forces. The author has collected and discusses here most of the important empirical formulæ, with the constants used by various designers and authorities upon everything from cylinder walls and heads, water jackets, areas of valves, cams, valve seats and stems, valve closure springs, piston length, barrel and rings, wrist pins, connecting rods, cranks and crank pins, to those upon twisting and bending moments, main bearings, journal pressures, and fly wheels.

The book is attractive in appearance and contains but very few typographical errors. It will undoubtedly prove of great assistance to those engaged in the actual design of gas engines, and should find a place in every engineering library.

CHARLES W. BERRY.

Analysis of Ores[1]

This excellent volume is written for the use of the technician as well as the student, and should be appreciated by both. It aims to describe, in sufficient detail to be immediately and practically useful, methods which, so far as such a thing is possible, may be applied to the common run of problems which the practicing ore analyst is called upon to solve. These methods have been selected in part from those devised and tested during the author's own extended experience, and in part from recognized authorities. In the latter case the descriptions are often amplified, and valuable suggestions are interpolated.

The chapters treat successively of apparatus, electrolysis, logarithms, the determination of aluminium, antimony, arsenic, barium, bismuth, cadmium, calcium, chlorine, chromium, copper, iron, lead, magnesium, manganese, mercury, molybdenum, nickel and cobalt, phosphorus, potassium and sodium, silica, sulphur, tin, titanium, tungsten, uranium and vanadium, zinc, the combining of determinations, and the analysis of boiler waters, of coal and coke, and of crude petroleum. Useful tables are given at the close of the book, and the volume is well indexed.

The author's words of caution in his preface regarding the ill-advised haste with which untested modifications are often introduced by the analyst when ostensibly following a published analytical procedure, often rendering it practically valueless (and incidentally occasioning unjustified criticism of its author), are worthy of serious attention.

Some differences of opinion as to this or that detail in a work of this character are bound to occur to every thoughtful reader; but these will surely not alter the broader verdict that Mr. Low has made a valuable and helpful contribution to chemical literature.

H. P. Talbot.

High-Tension Power-Transmission[2]

"*Resolved*, That a Committee on High-Tension Transmission, consisting of five members, may be appointed for the purpose of collecting

[1] Technical Methods of Ore Analysis. By Albert H. Low, B.S. New York: John Wiley & Sons, 1905. vi + 273 pp.

[2] High-Tension Power-Transmission. A Series of Papers and Discussions Presented at the Meetings of the American Institute of Electrical Engineers, under the Auspices of the Committee on High-Tension Transmission. New York: McGraw Publishing Co., 1905.

data respecting present practice in electric transmission at high voltage, and of presenting a report which will indicate the successful methods which are now in operation in such form as to be of immediate value to electrical engineers. It is within the scope of the committee to secure data upon line construction, insulators, insulator pins, and the like, and the conditions of operation at different voltages and under different climatic conditions; to investigate methods of testing insulators, and to indicate the method or methods which in its judgment are superior. Also to ascertain the methods employed for voltage regulation, the conditions attendant upon the switching of high-tension circuits, and to collect data respecting lightning and static disturbances and the use of grounded protective wires."

This resolution, passed by the Board of Directors of the American Institute of Electrical Engineers on September 26, 1902, marks a distinct step in advance in the relations of engineering societies to the progress of engineering in this country. To be sure, the province of the special committee appointed in accordance with its provision was limited to one particular engineering problem, that of high-tension power-transmission. This problem, however, is of so varied an aspect, involving great variety of conditions and many related problems in electrical and structural engineering, that the area covered is of necessity a large one. Very wisely, as it seems to the writer, the committee appointed to consider the question adopted two methods for securing information. The first was to send out printed lists of questions to the various transmission plants in the country, with a request that answers to the questions be filled in and the lists returned. In addition to this, discussions on chosen topics were instituted at stated meetings of the American Institute of Electrical Engineers, being preceded on each occasion by an introductory paper given by some member of the Institute of prominence in transmission work.

The results of both these methods are given in a volume of 466 pages, something less than one hundred of which are concerned with the replies to questions of the printed lists. The introductory papers are twenty-five in number, and these, with the accompanying discussions, involve contributions by more than one hundred of the prominent engineers in the United States. The mechanical construction of transmission lines, the problems involving choice and arrangement of apparatus for the successful operation and maintenance of the system, and devices for its protection are some of the more important

topics discussed. The result is eminently satisfactory, and the volume is of great value as giving in compact form a very considerable amount of valuable information on high-tension power-transmission. If there is one criticism which the writer feels may be offered, it is that there is very little expression concerning actual troubles which have been met with by the operating engineers, although the frank expression of one's difficulties, perhaps, ought not to be expected before the millennium; yet it would be of the greatest value to have a volume of "troubles" published under the auspices of our engineering societies. The volume is well indexed, both as to subjects and authors.

H. E. Clifford.

Food Analysis[1]

In the second edition of this well-known book the general plan and scope of the work remain as before. The volume is not greatly altered in size, but many changes have been made in the subject-matter with a view to keeping pace with progress in the field of food analysis — a field in which, as the authors well say, American work is rapidly becoming the leader.

The new matter which has been added includes new processes for the detection of natural colors used as substitutes for the fruit and egg colors; improved methods for the detection of formaldehyde and saccharin; rapid methods for the routine examination of vanilla and lemon extracts, and for the estimation of fat in condensed milk and in cereal foods; analytical data concerning fruit juices, jams, and jellies; and the detection of palm oil in oleomargarine. Many minor changes and improvements in processes have been made.

The methods described have been very largely brought up to date, and the selection, necessary in a work so largely a compilation, has been judiciously done in most cases. Naturally some things will be looked for in vain. It would have seemed better, perhaps, to give in greater detail the use of the refractometer, an instrument now in daily use in every laboratory concerned with food analysis. The new immersion refractometer, which is certain to prove of the greatest usefulness in

[1] Select Methods in Food Analysis. By Henry Leffmann and William Beam. Second edition. Philadelphia: Blakiston's, 1905. $2.50.

this work, is dismissed with a line or two. The directions given for many of the processes appear suggestive rather than based on actual experience in laboratory practice.

Considerable improvement is noted over the previous edition in regard to the matter of references. The number of these given is nearly doubled. It is a matter of regret, however, that the authors did not see fit to go still further. It is, too, somewhat amusing to note the strenuous efforts of the authors to avoid any mention of the Babcock test for fat in milk, so largely used in this country.

In the reviewer's opinion the book is one which will prove helpful not so much to the student as to the chemist engaged in actual work in food analysis. For him it offers a mass of information given in concise form. It provides for the busy worker all necessary data without the setting of needless information so often found in books of reference. In a word, it is a book for the practical worker, and the appearance of a second edition in so short a time is evidence that it has fulfilled its purpose.

A. G. WOODMAN.

THE CONSTITUTION OF HYDRAULIC MORTARS[1]

THIS is a translation of the paper published by Dr. Le Chatelier in the *Annales des Mines* for 1887, in which he made a complete study of the setting and hardening of Portland cements and hydraulic limes. Preliminary to the study of these materials is a study of the phenomena connected with the setting of plaster of Paris, and of the silicates of barium.

Part first is concerned with the subject of plaster. It gives an historical *résumé* of the study of the phenomena which take place in the calcination of plaster and of its setting, crystallization, and hardening. The result of this indicates "that the crystallization which accompanies the hardening of mortars results from the difference in solubility of the bodies which set and those which are formed during the set; the former occurring in a state of unstable equilibrium in the presence of

[1] Experimental Researches on the Constitution of Hydraulic Mortars. By Henri Le Chatelier. Translated from the French by Joseph Lathrop Mack. New York: McGraw Publishing Co., 1905. 128 pp., 8vo.

water, and being able to exist there only momentarily." A similar study was made of the silicates of barium.

The main body of the work is concerned with cements and hydraulic limes. It was in this paper that Le Chatelier, after studying the hydraulic properties of the various silicates and aluminates of lime, gave the ratios of the lime, magnesia, silica, and alumina in Portland cements which have been so largely quoted in works upon the subject.

The work is more of a chemical than of an engineering character, but it will be found instructive by all engineers who are interested in a detailed study of the constitution of cements and of the phenomena of setting and hardening.

The Berlin–Zossen Electric Railway Tests of 1903[1]

This book is of value to both civil and electrical engineers. It will be recalled that the high-speed tests on the Berlin-Zossen line were discontinued a few years ago because the track was found inadequate and required reconstruction; after this reconstruction was complete further tests were made, of which this volume gives the result.

The points at issue were, first, to determine the feasibility of supplying adequate power to a train moving at high speed; second, to ascertain the actual power required at such speeds; and third, to investigate the construction of roadway and rolling stock necessary to make such speeds safe. Experiments were made with reference to the proper form of trolley, and as a result the side-bearing triple-bow trolleys were used, designed in a very ingenious way. The results indicate that the apparatus, as finally perfected, is able to take off without trouble ample current for operating up to 120 or 130 miles per hour.

The determination of the power required for very high speeds was a very important object of the tests, since the train resistances at such high speeds were very imperfectly known. It was supposed by many that the air and track resistances would rise very rapidly, and indeed the whole subject was involved in much uncertainty. The tests have

[1] The Berlin-Zossen Electric Railway Tests of 1903. Translated by Franz Welz, with an introduction on the general subject of train resistance by Dr. Louis Bell. New York: McGraw Publishing Co., 1905. 58 pp., 38 plates, 4to.

gone far towards clearing up these points, and in this connection the admirable introduction by Dr. Louis Bell is of much interest to engineers. The electrical details of the tests will be found very interesting by electrical engineers, while civil engineers will be interested in the construction of the roadbed, which was found most satisfactory. The rails were about 40 feet long, weighing 82½ pounds per foot; eighteen ties were used per rail, and the curves had a radius of 2,000 meters, with an elevation of outer rail of a little over 3 inches. The effect upon the resistance of pointed noses on the head of the train was studied.

The detailed results of the tests and the description of the measuring instruments employed will be found of much interest and value. The work is a distinct contribution to our knowledge with reference to high speed traction.

Concrete, Plain and Reinforced[1]

This book is a veritable encyclopedia relating to concrete. In it will be found information on every important matter connected with the subject. It is the result of an enormous amount of work in collating information from other works and periodicals, and the material so collated has been well digested and is presented in an attractive and interesting form. It is the result of long study and investigation, especially on the part of Mr. Sanford E. Thompson, an Institute graduate of the class of 1889, and all Institute men should be proud that one of our alumni has distinguished himself by such an important contribution to engineering literature.

It is difficult to specify further with reference to this work, for it literally contains all the information of value at present available. It is well illustrated, accompanied by numerous diagrams, and at the end is an index of periodical literature which will be found valuable. It is also well indexed. The work contains chapters by Mr. Newberry, who is well known as an authority on the chemistry of the subject, and by Mr. Fuller, who has done so much in forwarding the use of concrete and in emphasizing the importance of a mechanical analysis of the

[1] A Treatise on Concrete, Plain and Reinforced. By Frederick W. Taylor and Sanford E. Thompson, with chapters by R. Feret, William B. Fuller, and Spencer B. Newberry. New York: John Wiley & Sons, 1905. 571 pp. and index, 8vo.

materials used, in order that the result may be as perfect and economical a concrete as possible. It also contains a chapter upon the effect of sea water, by Mr. Feret, who is well known as the author of an excellent French work on the subject.

The subject of reinforced concrete is clearly and adequately treated, the data for the formulæ being clearly presented and the resulting formulæ clearly demonstrated and compared. This portion of the work has been contributed by Professor McKibben. The book is one which no engineer can afford to be without. It is a source of satisfaction to learn that the work has been so well received that a new edition has been called for within a few months of its issue.

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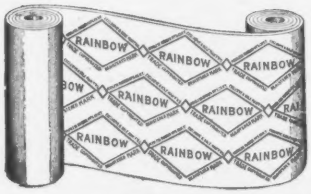

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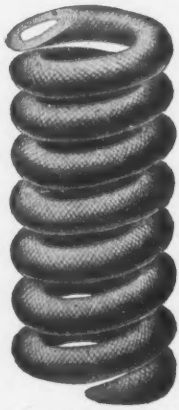

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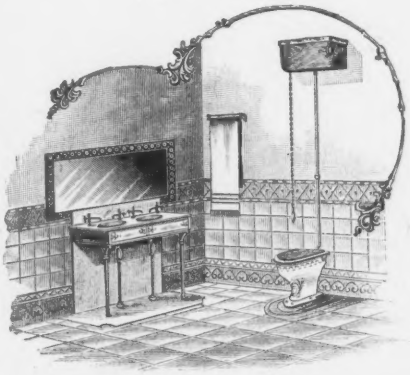

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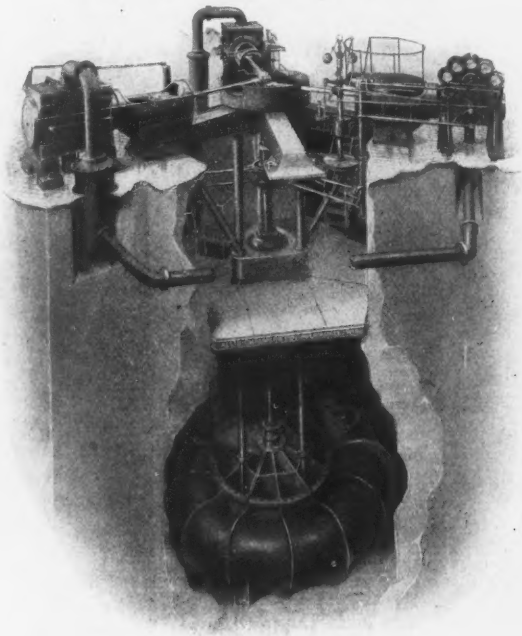

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